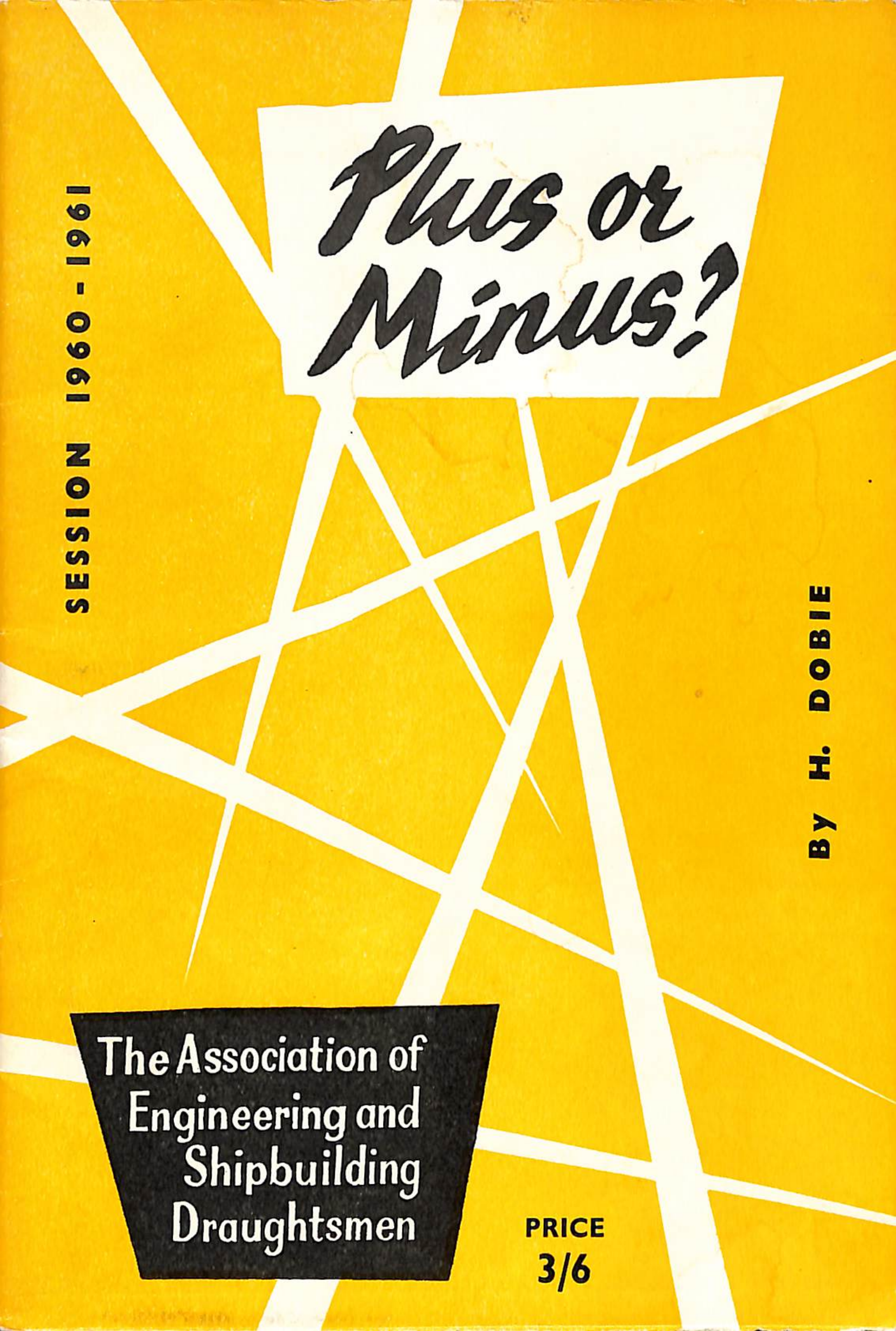

Plus or Minus?

SESSION 1960 - 1961

BY H. DOBIE

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"PLUS OR MINUS?"

A Study of the Application of Tolerances in Machining Operations

by

H. DOBIE

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By H. Dobie.

INTRODUCTION.

Owing to the influx of mass production methods in many factories, operation sheets are now being used. This booklet is primarily for draughtsmen engaged in the drawing up of such sheets, but will be useful for engineers in general.

An operation sheet shows, by thin lines, the part as the operator receives it, and any alteration in shape that takes place at that operation is shown by heavy lines, thereby denoting the surfaces to be machined.

The dimensioning of these sheets would be very simple if every dimension were "spot on," but as all dimensions have a tolerance, it is necessary to dimension the operation sheets in such a way that all the "finished part drawing" sizes will be achieved within the tolerance given. Tolerances are of three types. Unilateral, which extend in one direction only, all plus or all minus, from the basic or nominal size. Bilateral, which extend in both directions, but the plus and minus amounts are not equal. Bilateral, where the amounts are equal. Before commencing calculations the first two types should always be converted into the latter.

Dimensions are usually given to the nearest thousandth of an inch, *i.e.*, ·001″, and when calculating, it will be found that anything less than a thou. is best written as a fraction of a thousandth, as this will simplify the calculations, *i.e.*, ·002125″ would be written as ·002⅛″. This is not the usual practice, but it has been proved very successful when applied to operation sheet calculations. Confusion or a lot of unnecessary calculating may result from not using the thou. as a basis. The one exception is for the trigonometric calculations where seven decimal places will result from using trig. functions to four decimal places, but even these should be finally approximated to the nearest $\frac{1}{16}$ of a thou. This is quickly done by the use of the decimal equivalents chart.

The following thesis gives the sixteen fundamental rules and their application.

THESIS.

The Tolerance on a Dimension is the amount of deviation from the mean figure that is allowed, and must be worked to. For example, the "mean" figure of ·248″/·252″ is ·250″ and the tolerance is plus or minus ·002″. For calculation purposes it would be written as ·250″ ± ·002″. For the same reason, a dimension given as $\cdot 250''\,{}^{+\cdot 001''}_{+\cdot 005''}$ would be written as ·253″ ± ·002″. The importance of tolerances and their application to operation sheets is explained by the following rules and examples.

Fig. 1 (*a*) shows the finished part, and Fig. 1 (*b*) and 1 (*c*) the two operation drawings required, and the correct method of dimensioning. For clearness sake, only the dimensions connected with the problem have been shown.

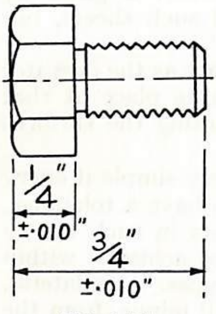


Fig. 1 (a).

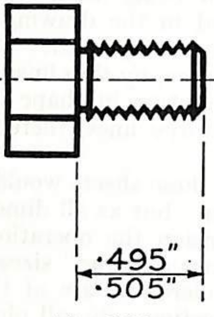


Fig. 1 (b).

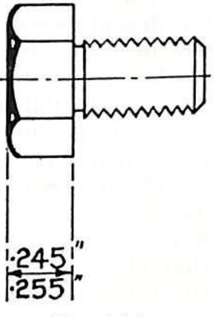


Fig. 1 (c).

The tolerance on the overall dimension is achieved by tightening up the tolerances on the width of the head and the length of the shank to ±·005″. The shortest length of shank permitted is ·495″ and the shortest width of head is ·245″, therefore the shortest overall length will be ·740″, *i.e.*, $\frac{3}{4}'' - \cdot 010''$. The greatest length of shank permitted is ·505″ and the greatest width of head is ·255″, therefore the greatest overall length will be ·760″, *i.e.*, $\frac{3}{4}'' + \cdot 010''$.

Mathematically, the problem would be written :—

$$\begin{array}{c} \cdot 500'' \pm \cdot 005'' \\ \cdot 250'' \pm \cdot 005'' \\ \hline \cdot 750'' \pm \cdot 010'' \\ \hline\hline \end{array}$$

Now, if the dimensions $\frac{1}{4}''$ and $\frac{1}{2}''$ had been given a tolerance of ±·010″, then the overall length achieved would have been any size between ·730″ and ·770″, therefore the $\frac{3}{4}'' \pm \cdot 010''$ dimension *would not have been maintained.*

If, instead of giving the width of the head in Fig. 1 (*c*), it had been necessary to give an overall length, this would be given as ·745″/·755″. The width of head, $\frac{1}{4}'' \pm \cdot 010''$, would therefore be achieved, as shown by the following :—

The shortest length of shank permitted is ·495″, and the greatest overall length is ·755″, therefore the greatest width of head will be ·260″, *i.e.*, $\frac{1}{4}''$ + ·010″. The greatest length of shank permitted is ·505″ and the shortest overall length is ·745″, therefore the smallest width of head will be ·240″, *i.e.*, $\frac{1}{4}''$ − ·010″.

Mathematically, the problem would be written :—

$$\begin{array}{r} \cdot750'' \pm \cdot005'' \\ \cdot500'' \pm \cdot005'' \\ \hline \cdot250'' \pm \cdot010'' \\ \hline \hline \end{array}$$

From these examples, it can be stated that :—

Rule 1.—The tolerance on any LENGTH is equivalent to the *sum* of the tolerances on the dimensions, added or subtracted to achieve the length.

It is often necessary with parts that have "ground" faces, to know the exact tolerance on the amount to be removed by grinding. Fig. 2 (*a*) shows the turning operation, and Fig. 2 (*b*) the grinding operation, on a plug.

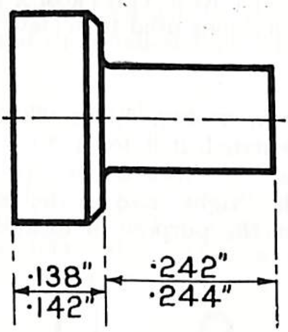


Fig. 2 (a).

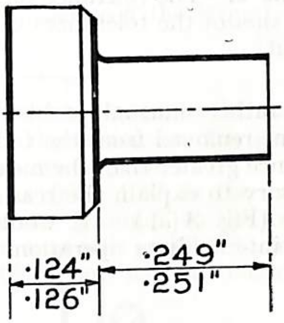


Fig. 2 (b).

To find the tolerance on the amount removed by grinding from the chamfered face, convert ·242″/·244″ and ·249″/·251″ into ·243″ ± ·001″ and ·250″ ± ·001″ respectively, then the mean figure of the amount removed is obviously ·007″. The tolerance on this figure is ±·002″, as will be readily understood by the following explanation :—

The greatest turned length of the shank is ·244″ and the shortest "ground" length is ·249″, therefore the minimum amount it is possible to remove is ·005″, *i.e.*, ·007″ − ·002″. The shortest turned length of the shank is ·242″ and the greatest "ground" length is ·251″, therefore the maximum amount it is possible to remove is ·009″, *i.e.*, ·007″ + ·002″.

Mathematically, this would be written :—

$$\begin{array}{r} \cdot250'' \pm \cdot001'' \\ \cdot243'' \pm \cdot001'' \\ \hline \cdot007'' \pm \cdot002'' \\ \hline\hline \end{array}$$

To find the tolerance on the amount removed by grinding from the plain face, first find the overall lengths and their tolerances by using Rule 1.

The turned length will be found to be ·383″ ± ·003″ and the "ground" length ·375″ ± ·002″. The mean figure of the amount removed is obviously ·008″ and the tolerance on this figure ±·005″.

The same proof, as used for the chamfered face, can be applied in this instance, and mathematically this would be written :—

$$\begin{array}{r} \cdot383'' \pm \cdot003'' \\ \cdot375'' \pm \cdot002'' \\ \hline \cdot008'' \pm \cdot005'' \\ \hline\hline \end{array}$$

From these examples it can be stated that :—

Rule 2.—The tolerance on an AMOUNT REMOVED FROM A FACE is the *sum* of the tolerances of the dimensions used to achieve that amount.

A rather unusual problem is shown in Fig. 3, for when the amount removed from the face is calculated, it is found to have a tolerance greater than the mean figure. At this stage, it is perhaps necessary to explain the reason for the "tight" size on the turned flange (Fig. 3 (*a*)). It would be for the purpose of location at some intermediate operation.

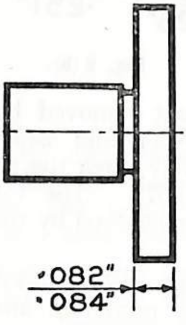


Fig. 3 (a).

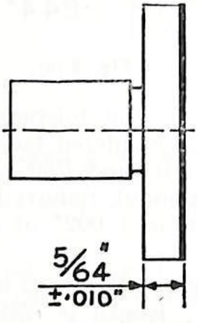


Fig. 3 (b).

Using Rule 2, it is found that ·083″ ± ·001″ minus ·078″ ± ·010″ equals ·005″ ± ·011″. The figure we have achieved is useless for calculation purposes, as it is impossible to take ·005″ − ·011″ off the face, *i.e., put* ·006″ *on* ! Therefore, as the face must be touched, it can be stated that the minimum amount that will be removed is ·002″.

The maximum amount will be ·016″, *i.e.,* ·005″ + ·011″. Thus ·002″/·016″ is the actual amount it is possible to remove and ·005″ ± ·011″ in theory becomes ·009″ ± ·007″ in practice.

The following proof should make this clear :—

The greatest width of the turned flange, shown in Fig. 3 (*a*), is ·084″ and the smallest width of the "ground" flange, shown in Fig. 3 (*b*), is ·068″, therefore the maximum amount it is possible to remove is ·016″.

The smallest width of the turned flange is ·082″ and the greatest width of the "ground" flange is ·088″, therefore, as the width cannot be increased and *must be decreased,* it can be stated that the minimum amount removed will be ·002″.

Mathematically, this would be written :—

·005″ ± ·011″ = ·002″/·016″ = ·009″ ± ·007″.

Rule 3.—(For use when, after using Rule 2, the tolerance is found to be greater than *two thou. less* than the mean figure, *e.g.,* mean figure ·005″ minus ·002″ equals ·003″). The minimum amount removed from the face will be ·002″. The maximum amount removed will be the difference between the largest rough size and the smallest finished size.

When a part has a very small amount to be removed from each face, it is possible to give only one dimension on the grinding operation as opposed to the method shown at Rule 2.

In Fig. 4 (*a*), a washer is faced to ·098″/·102″ in the turning operation, and in Fig. 4 (*b*) both faces are "ground" to the finished size of ·093″/·095″. The maximum amount it is possible to remove from the faces is ·009″, *i.e.,* ·102″ − ·093″, but, as both faces must

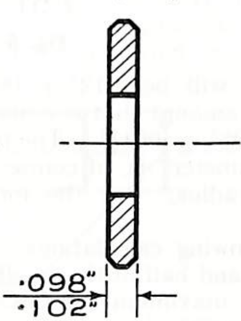


Fig. 4 (a).

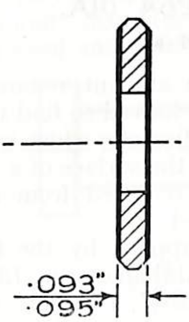


Fig. 4 (b).

be ground, it is practical to state that ·002″ would be the minimum amount removed from one face, thereby leaving ·007″ as the maximum amount removed from the other face.

This statement is proved by the following :—

The greatest turned width of the washer is ·102″ and ·002″ is the minimum that it is practical to remove from a face by grinding, therefore ·100″ is the greatest width after one face has been ground. The smallest "ground" width of the washer is ·093″, therefore ·007″ is the maximum it is possible to remove from a face. Obviously, either face could have the maximum or minimum amount removed, consequently ·004½″ ± ·002½″, *i.e.*, ·002″/·007″ is the amount it is possible to remove from either face.

Mathematically, this would be written :—

$$\cdot 102'' - \cdot 093'' = \cdot 009'' = \cdot 002''/\cdot 007'' = \cdot 004\tfrac{1}{2}'' \pm \cdot 002\tfrac{1}{2}''.$$

Rule 4.—(For use when grinding two faces which are tied by a dimension and neither of these faces is tied to a fixed face in the grinding operation. It can be used to advantage when the grinding allowance is very small). The minimum amount removed from either face will be ·002″. The maximum amount removed will be the difference between the smallest finished size and the largest rough size, minus ·002.″

The tolerance on the amount ground off the surface of a diameter either internal or external, is calculated in the same way as for a face, but the result is halved. Fig. 5 (*a*) shows a diameter turned to ·262″ ± ·002″ and Fig. 5 (*b*) shows this diameter ground to ·250″ ±·001″. The amount removed will be ·012″ ± ·003″, but this figure must be halved to find the amount that is removed from the *surface* of the diameter which is ·006″ ± ·001½″. The term "amount removed from the surface of a diameter" is, of course, the same as "the amount removed from a radius," but the former is more commonly used.

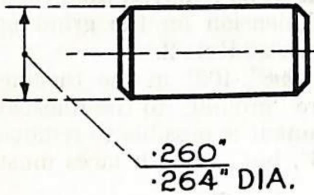


Fig. 5 (a).

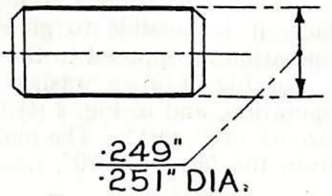


Fig. 5 (b).

Proof is supplied by the following calculations. Half of the greatest turned diameter is ·132″ and half of the smallest "ground" diameter is ·124½″, therefore the maximum amount it is possible to remove from the surface is ·007½″, *i.e.*, ·006″ + ·001½″. Half of the smallest turned diameter is ·130″ and half of the greatest "ground" diameter is ·125½″, therefore the minimum amount it is possible to remove is ·004½″, *i.e.*, ·006″ – ·001½″.

Mathematically, this would be written :—

$$\begin{array}{c} \cdot262'' \pm \cdot002'' \\ \cdot250'' \pm \cdot001'' \\ \hline \cdot012'' \pm \cdot003'' \\ \hline\hline \end{array}$$

$$\frac{\cdot012'' \pm \cdot003''}{2} = \cdot006'' \pm \cdot001\tfrac{1}{2}''.$$

Rule 5.—The tolerance on the AMOUNT REMOVED FROM THE SURFACE OF A BORE OR A DIAMETER is *half the sum* of the tolerances on the rough and finished diameters.

The following problem is rather similar to the one described at Fig. 3. The "tight" size on the turned diameter is for the purpose of location at an intermediate operation.

If Rule 5 is used on the part shown at Fig. 6, it will be found that the tolerance on the amount removed from the surface of the diameter is greater than the mean figure.

The amount removed in theory will be ·004″ ± ·006″, *i.e.*, half of ·258″ ± ·002″ minus half of ·250″ ± ·010″. In practice (as previously explained in Rules 3 and 4), ·002″ will be the minimum removed, as the surface must be touched, and it is obviously impossible to remove ·004″ – ·006″, *i.e.*, *put* ·002″ *on* ! The maximum amount will be ·004″ + ·006″, therefore ·002″/·010″ is the actual amount it is possible to remove from the surface of the diameter, and ·004″ ± ·006″ in theory becomes ·006″ ± ·004″ in practice.

The following proof should make this clear :—

Half of the greatest turned diameter, shown in Fig. 6 (*a*), is ·130″ and half of the smallest "ground" diameter, shown in Fig. 6 (*b*), is ·120″, therefore the maximum amount it is possible to remove from the surface is ·010.″ Half of the smallest turned diameter is ·128″ and half of the greatest "ground" diameter is ·130″, therefore, as the diameter cannot be increased and *must be decreased*, it

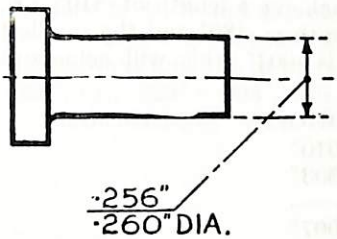


Fig. 6 (a).

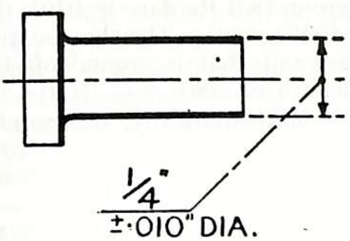


Fig. 6 (b).

can be stated that the minimum amount removed will be ·002″.

Mathematically, the problem would be written :—

$$\cdot004'' \pm \cdot006'' = \cdot002''/\cdot010'' = \cdot006'' \pm \cdot004''.$$

Rule 6.—(For use when, after using Rule 5, the tolerance is found to be greater than, *two thou. less* than the mean figure, *i.e.*, mean figure ·004″ minus ·002″ equals ·002″). The minimum amount removed from the surface of the diameter will be ·002″. The maximum amount removed will be half of the difference between the largest rough diameter and the smallest finished diameter.

The following example shows the necessity of knowing the tolerance on the amount being removed from any "face."

What must be the length of the shank in the turning operation, Fig. 7 (*a*), to achieve a length of ½″ ± ·010″ when the face is ground to the dimension shown in Fig. 7 (*b*) ?

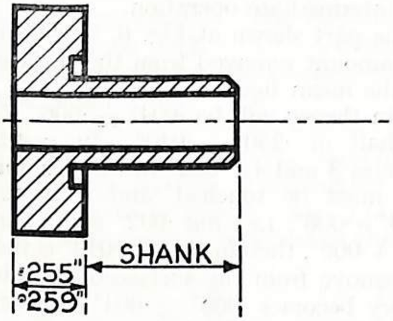


Fig. 7 (a).

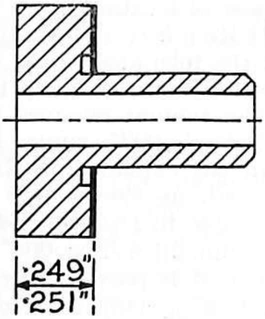


Fig. 7 (b).

It is found by using Rule 2, that ·004″/·010″ will be removed from the face by grinding, therefore the turned length should be ·500″ ± ·010″ minus ·007″ ± ·003″. This equals ·493″ ± ·007″ and can be proved by the following explanation. The greatest turned length is ·500″ and the greatest amount that is allowed to be ground off the face is ·010″, this will achieve a length of ·510″, *i.e.*, ·500″ + ·010″. The shortest turned length is ·486″ and the smallest amount that is ground off the face is ·004″, this will achieve a length of ·490″, *i.e.*, ·500″ − ·010″.

Mathematically, this would be written :—

$$\begin{array}{c} \cdot500'' \pm \cdot010'' \\ \cdot007'' \pm \cdot003'' \\ \hline \cdot493'' \pm \cdot007'' \\ \hline \hline \end{array}$$

By applying Rule 1 we have further proof. Overall length of the part would be ·750″ ± ·009″, *i.e.*, ·257″ ± ·002″ plus ·493″ ± ·007″. The finished head width is ·250″ ± ·001″, therefore the finished shank length would be ·500″ ± ·010″.

Mathematically, this would be written :—

·257″ ± ·002″	·750″ ± ·009″
·493″ ± ·007″	·250″ ± ·001″
·750″ ± ·009″	·500″ ± ·010″

Rule 7.—The tolerance on a "ROUGH LENGTH" is the tolerance on the finished length *minus* the tolerance on the amount to be removed.

The next example is the reverse of that shown in Fig. 7. What will be the length of the shank in the grinding operation, Fig. 8 (*b*), if the turned length shown in Fig. 8 (*a*) is ·618″ ± ·002″ and ·007″ ± ·003″ is to be removed by grinding?

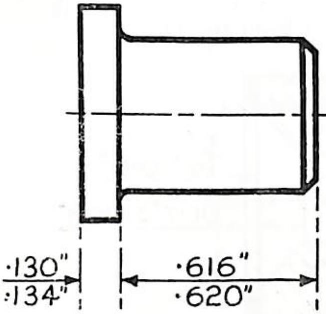


Fig. 8 (a).

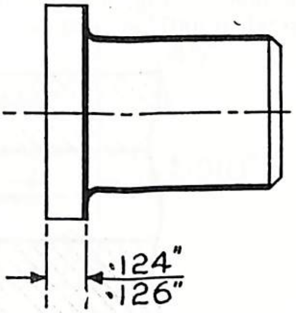


Fig. 8 (b).

The amount removed from the face will obviously increase the length of the shank and the tolerance will be greater. ·618″ ± ·002″ plus ·007″ ± ·003″ equals ·625″ ± ·005″.

This can be proved by the usual method that the greatest turned length is ·620″ and the greatest amount to be removed from the face is ·010″ and therefore ·630″, *i.e.*, ·625″ + ·005″, will be the greatest length achieved. The shortest turned length is ·616″ and the smallest amount to be removed from the face is ·004″, therefore ·620″, *i.e.*, ·625″ – ·005″, will be the shortest length achieved.

Mathematically, this would be written :—

·618″ ± ·002″
·007″ ± ·003″

·625″ ± ·005″

This can also be proved by using Rule 1. The overall length is ·750″ ± ·004″, *i.e.*, ·618″ ± ·002″ plus ·132″ ± ·002″ and the finished width of the head is ·125″ ± ·001″, therefore the finished length of the shank is ·625″ ± ·005″, *i.e.*, ·750″ ± ·004″ minus ·125″ ± ·001″.

Mathematically, this would be written :—

$$\begin{array}{r} \cdot618'' \pm \cdot002'' \\ \cdot132'' \pm \cdot002'' \\ \hline \cdot750'' \pm \cdot004'' \\ \hline\hline \end{array} \qquad \begin{array}{r} \cdot750'' \pm \cdot004'' \\ \cdot125'' \pm \cdot001'' \\ \hline \cdot625'' \pm \cdot005'' \\ \hline\hline \end{array}$$

Rule 8.—The tolerance on a "FINISHED LENGTH" is the tolerance on the rough length *plus* the tolerance on the amount removed.

Other problems, often encountered, are chamfers and countersunk holes. Fig. 9 shows a chamfer which has to be $\frac{1}{16}$″ ± ·010″ deep when ·007″ ± ·003″ is removed from the face.

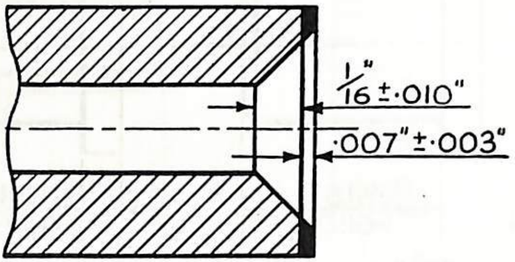


Fig. 9.

No angle has been shown, as this problem is common to all angles and can be solved by the same method as used for Fig. 7. Remembering that the amount removed from the face must be added to the finished depth in this case, the "rough" depth of the chamfer will therefore be ·062½″ ± ·010″ plus ·007″ ± ·003″, which equals ·069½″ ± ·007″.

The usual proof can be applied as follows :—

The greatest "rough" depth of chamfer is ·076½″, *i.e.*, ·069½″ + ·007″ and the smallest amount removed from the face is ·004″, therefore ·072½″, *i.e.*, $\frac{1}{16}$″ + ·010″ will be the greatest finished depth of chamfer. The smallest "rough" depth of chamfer is ·062½″, *i.e.*, ·069½″ − ·007″ and the greatest amount removed from the face is ·010″, therefore ·052½″, *i.e.*, $\frac{1}{16}$″ − ·010″ will be the smallest finished depth of chamfer.

Mathematically, the problem would be written :—

$$\begin{array}{l} \cdot062\tfrac{1}{2}'' \pm \cdot010'' \\ \cdot007'' \ \ \pm \cdot003'' \\ \hline \cdot069\tfrac{1}{2}'' \pm \cdot007'' \\ \hline\hline \end{array}$$

Rule 9.—The tolerance on the "ROUGH DEPTH" OF ANY CHAMFER is the tolerance on the finished depth *minus* the tolerance on the amount removed from the face.

Fig. 10 shows a 45° chamfer, which has to be $\frac{1}{16}''$ ± ·010″ deep when ·006″ ± ·001½″ has been removed from the surface of the bore. It must be remembered that as two sides of a 45° triangle are equal, any amount removed in the vertical direction will be the same as that removed in a horizontal direction, or, *vice versa*, and the depth must therefore be increased by ·006″ ± ·001½″.

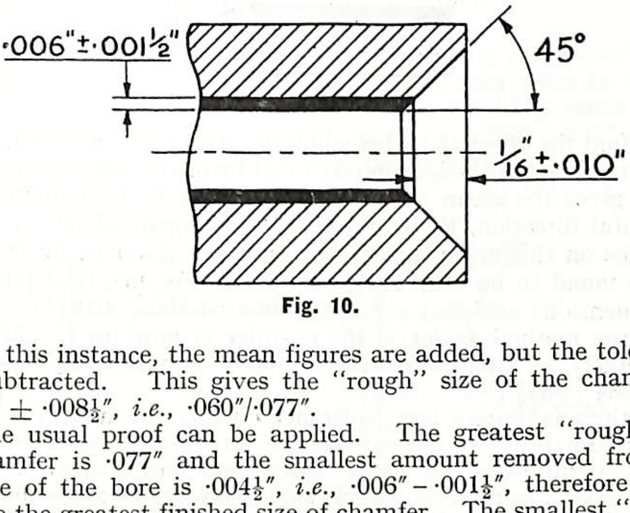


Fig. 10.

In this instance, the mean figures are added, but the tolerances are subtracted. This gives the "rough" size of the chamfer as ·068½″ ± ·008½″, *i.e.*, ·060″/·077″.

The usual proof can be applied. The greatest "rough" size of chamfer is ·077″ and the smallest amount removed from the surface of the bore is ·004½″, *i.e.*, ·006″ – ·001½″, therefore ·072½″ will be the greatest finished size of chamfer. The smallest "rough" size of chamfer is ·060″ and the greatest amount removed from the surface of the bore is ·007½″, *i.e.*, ·006″ + ·001½″, therefore ·052½″ will be the smallest finished size of chamfer.

Mathematically, this would be written :—

$$\begin{array}{l} \cdot062\tfrac{1}{2}'' \pm \cdot010'' \\ \cdot006'' \ \ \pm \cdot001\tfrac{1}{2}'' \\ \hline \cdot068\tfrac{1}{2}'' \pm \cdot008\tfrac{1}{2}'' \\ \hline\hline \end{array}$$

Rule 10.—The tolerance on the "Rough Depth" of a 45° Chamfer is the tolerance on the finished size *minus* the tolerance on the amount removed from the surface of the bore, or the diameter.

Chamfers at other than 45° are more complicated and are solved in the following manner. Fig. 11 shows a common 60° centre by $\frac{1}{16}''$ ± ·010″ deep. This obviously gives a 30° chamfer. The amount to be removed from the surface of the bore is ·007″ ± ·002″, therefore the chamfer is affected by that amount in a *vertical* direction.

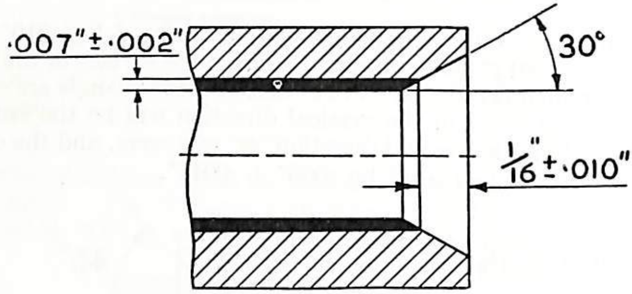


Fig. 11.

To find the effect that this will have on the depth (which is in a *horizontal* direction), trigonometry must be used. ·007″ × cotangent of 30° gives the mean figure of the amount to be removed in a horizontal direction, therefore ·002″ × cotangent of 30° gives the tolerance on this mean figure. The amount removed horizontally will be found to be ·012124″ ± ·003464″. For practical purposes, the dimensions achieved are approximated thus, ·012⅛″ ± ·003½″. The same method as for a 45° chamfer is now used. Finished depth ·062½″ ± ·010″ plus ·012⅛″ ± ·003½″ equals ·074⅝″ ± ·006½″, *i.e.*, ·068⅛″/·081⅛″.

As there is quite a large tolerance on this dimension it is usual to approximate to the nearest thou., as previously explained. The "rough" depth of the 60° centre will appear on the operation sheet as ·069″/·081″, as approximations should always be made inwardly.

The following proof should make this clear :—

The greatest "rough" size of chamfer is ·081″, and the smallest amount removed from the surface of the bore in a horizontal direction is ·008⅝″, *i.e.*, ·012⅛″ − ·003½″, therefore ·072⅜″ will be the greatest finished depth of chamfer. The smallest "rough" size of chamfer is ·069″, and the greatest amount removed is ·015⅝″, *i.e.*, ·012⅛″ + ·003½″, therefore ·053⅜″ will be the smallest finished depth of chamfer.

The slight variation between "finished part drawing" size, ·052½″/·072½″, and the achieved finished size, ·053⅜″/·072⅜″, has been caused by approximating the calculations, but the achieved depth comes within the finished size and is the best that can be done, for practical reasons.

Mathematically, the calculation of this problem would be written thus :—

$$\begin{aligned} \cdot 007'' \times \text{cot. } 30^\circ &= \cdot 012\tfrac{1}{8}'' \text{ approx.} \\ \cdot 002'' \times \text{cot. } 30^\circ &= \cdot 003\tfrac{1}{2}'' \text{ approx.} \end{aligned}$$

$$\begin{array}{r} \cdot 062\tfrac{1}{2}'' \pm \cdot 010'' \\ \cdot 012\tfrac{1}{8}'' \pm \cdot 003\tfrac{1}{2}'' \\ \hline \cdot 074\tfrac{5}{8}'' \pm \cdot 006\tfrac{1}{2}'' \\ \hline\hline \end{array}$$

$$\cdot 074\tfrac{5}{8}'' \pm \cdot 006\tfrac{1}{2}'' = \cdot 068\tfrac{1}{8}''/\cdot 081\tfrac{1}{8}'' = \cdot 069''/\cdot 081'' \text{ approx.}$$

Rule 11.—The tolerance on the "ROUGH DEPTH" of a CHAMFER AT OTHER THAN 45° is the tolerance on the finished size, *minus* the cotangent of the angle times the tolerance on the amount to be removed from the surface of the bore, or the diameter. 45° chamfers are only excluded from this rule as it is unnecessarily complicated by the cotangent, cotangent of 45° being 1·000.

It is often necessary to find the tolerance on the *diameter* of a 90° countersink, or a 45° chamfer, which has been given as a depth (see Fig. 12). To maintain the depth of ·035″ the mean figure of the diameter must obviously be ·320″, *i.e.*, ·250″ + ·035″ + ·035″. The tolerance on this diameter will be ±·009″, *i.e.*, ·005″ + ·005″ − ·001″.

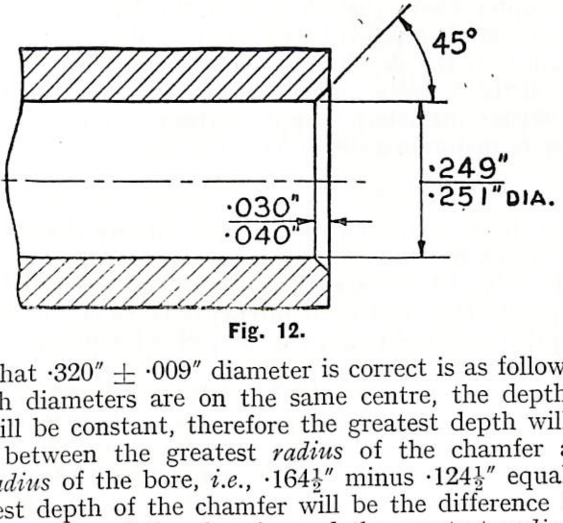


Fig. 12.

Proof that ·320″ ± ·009″ diameter is correct is as follows :—

As both diameters are on the same centre, the depth of the chamfer will be constant, therefore the greatest depth will be the difference between the greatest *radius* of the chamfer and the smallest *radius* of the bore, *i.e.*, ·164½″ minus ·124½″ equals ·040″. The smallest depth of the chamfer will be the difference between the smallest *radius* of the chamfer and the greatest *radius* of the bore, *i.e.*, ·155½″ minus ·125½″ equals ·030″.

Mathematically, the problem would be written :—

$$2\,(\cdot035'' \pm \cdot005'') = \cdot070'' \pm \cdot010''$$

$$\begin{array}{r} \cdot070'' \pm \cdot010'' \\ \cdot250'' \pm \cdot001'' \\ \hline \cdot320'' \pm \cdot009'' \\ \hline \hline \end{array}$$

If the *diameter* of a 45° chamfer is given and it is necessary to find the *depth* which will achieve this diameter, a similar calculation is made, thus :—

Say the diameter to be achieved is ·320″ ± ·009″, then the depth of chamfer must be made ·035″ ± ·004″. This is proved by adding the greatest size of the bore to twice the greatest depth of the chamfer, to find the greatest diameter of chamfer achieved, *i.e.*, ·251″ plus ·078″ equals ·329″. The smallest bore diameter plus twice the smallest depth of the chamfer is the smallest diameter of chamfer achieved, *i.e.*, ·249″ plus ·062″ equals ·311″.

Mathematically, this would be written :—

$$\begin{array}{r} \cdot320'' \pm \cdot009'' \\ \cdot250'' \pm \cdot001'' \\ \hline \cdot070'' \pm \cdot008'' \\ \hline \hline \end{array}$$

$$\tfrac{1}{2}\,(\cdot070'' \pm \cdot008'') = \cdot035'' \pm \cdot004''.$$

Rule 12.—The tolerance on the diameter of a 90° countersink or a 45° chamfer is *twice* the tolerance on the depth (or width) *minus* the tolerance on the finished bore (or outside diameter). Inversely, the tolerance on the depth is *half* of the difference between the tolerance on the diameter of the chamfer and the tolerance on the bore (or outside diameter). Applies where it is necessary to give a diameter to maintain a depth or *vice versa.*

To find the tolerance on the diameter of any chamfer at other than 45°, which has been given as a depth, the following method is applied. Fig. 13 shows a 60° centre by $\frac{1}{16}''$ ± ·010″ deep. The mean figure of the diameter will obviously be twice the mean figure of the depth times the tangent of 30°, plus the mean figure of the bore, *i.e.*, $2 \times \cdot062\tfrac{1}{2}'' \times \tan 30° + \cdot250''$. This equals ·322175″, or for practical purposes $\cdot322\tfrac{3}{16}''$. The tolerance on this mean figure will be twice the tolerance on the depth times the tangent of 30°, *minus* the tolerance on the bore, *i.e.*, $2 \times \cdot010'' \times \tan 30° - \cdot001''$. This equals ·010548″, or for practical purposes $\cdot010\tfrac{9}{16}''$.

Consequently, to achieve the correct tolerance on the depth of the chamfer, the diameter must be given as $\cdot322\tfrac{3}{16}'' \pm \cdot010\tfrac{9}{16}''$, *i.e.*, $\cdot311\tfrac{5}{8}''/\cdot332\tfrac{3}{4}''$. As previously explained, this dimension must

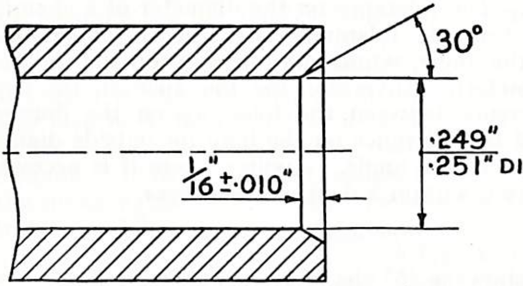


Fig. 13.

be approximated inwardly to the nearest thou. and the dimension on the operation sheet would be ·312″/·332″.

To prove these statements the usual method is applied. The greatest depth of chamfer will be, half of the difference between the greatest diameter and the smallest bore, times the cotangent of 30°, *i.e.*, $\frac{1}{2}$ (·332″ − ·249″) × cot 30°. This equals ·071$\frac{7}{8}$″ approximately. The smallest depth of chamfer will be, half of the difference between the smallest diameter and the largest bore, times the cotangent of 30°, *i.e.*, $\frac{1}{2}$ (·312″ − ·251″) × cot 30°. This equals ·052$\frac{13}{16}$″ approximately.

The achieved finished size (·052$\frac{3}{16}$″/·071$\frac{7}{8}$″), comes within the "finished part drawing" size (·052$\frac{1}{2}$″/·072$\frac{1}{2}$″), the slight variation having been caused by approximating the calculations.

Mathematically, the problem would be written :—

$2 \times \cdot062\frac{1}{2}'' \times \tan 30^\circ + \cdot250'' = \cdot322\frac{3}{16}''$ approx.
$2 \times \cdot010'' \times \tan 30^\circ - \cdot001'' = \cdot010\frac{9}{16}''$ approx.
$\cdot322\frac{3}{16}'' \pm \cdot010\frac{9}{16}'' = \cdot311\frac{5}{8}''/\cdot332\frac{3}{4}'' = \cdot312/\cdot332''$ approx.

If the *diameter* of a chamfer at other than 45° is given, and is necessary to find the *depth* which will achieve this diameter, similar calculation is made, thus :—

Say the diameter to be achieved is ·322″ ± ·010″, then the depth of chamfer must be made ·055″/·070″, *i.e.*, ·062$\frac{3}{8}$″ ± ·007$\frac{3}{4}$″ approximated. This is proved by adding twice the greatest depth of chamfer times the tangent of 30° to the greatest bore, *i.e.*, ·251″ + 2 (·070″ × tan 30°). This equals ·331$\frac{13}{16}$″ approximately, and is the greatest diameter of chamfer achieved. The smallest diameter achieved is, twice the smallest depth of chamfer times the tangent of 30°, plus the smallest bore, *i.e.*, ·249″ + 2 (·055″ × tan 30°). This equals ·312$\frac{1}{2}$″ approximately. The achieved finished size (·312$\frac{1}{2}$″/·331$\frac{13}{16}$″) comes within the "finished part drawing" size (·312″/·332″).

Mathematically, the problem would be written :—

$\frac{1}{2}\ (\cdot322'' - \cdot250'') \times \cot 30^\circ = \cdot062\frac{3}{8}''$ approx.
$\frac{1}{2}\ (\cdot010'' - \cdot001'') \times \cot 30^\circ = \cdot007\frac{3}{4}''$ approx.
$\cdot062\frac{3}{8}'' \pm \cdot007\frac{3}{4}'' = \cdot054\frac{5}{8}''/\cdot070\frac{1}{8}'' = \cdot055''/\cdot070''$ approx.

Rule 13.—The tolerance on the diameter of a chamfer at other than 45° is, *twice* the tolerance on the depth (or length) times the tangent of the angle, *minus* the tolerance on the finished bore (or outside diameter). Inversely, the tolerance on the depth is *half* of the difference between the tolerance on the diameter of the chamfer and the tolerance on the bore (or outside diameter) times the cotangent of the angle. Applies where it is necessary to give a diameter to maintain a depth or *vice versa*.

Fig. 14 shows a 45° chamfer with a finished diameter of ·500″ ±·010″. As the face is to be ground at a later operation, it is necessary to know the tolerance on the "rough" diameter. ·008″ ±·002″ is the amount to be removed, therefore, as shown by previous examples, the mean figure of the rough diameter will be ·516″, *i.e.*, ·500″ + ·008″ + ·008″. The tolerance will be ·006″, *i.e.*, ·010″ − (·002″ + ·002″), giving the size of the rough diameter as ·516″ ± ·006″, or ·510″/·522″.

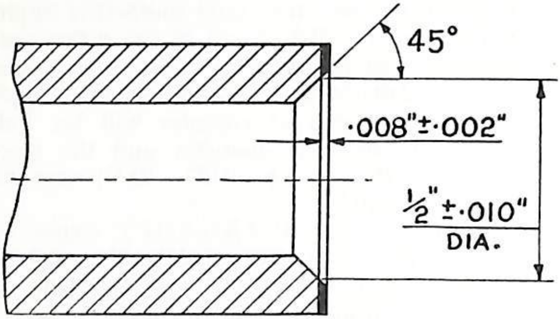


Fig. 14.

Proof is supplied by the usual method. The greatest rough diameter of the chamfer, minus twice the smallest amount removed from the face, equals the greatest finished diameter of chamfer, *i.e.*, ·522″ − (·006″ × 2) = ·510″. The smallest rough diameter of the chamfer, minus twice the greatest amount removed from the face, equals the smallest finished diameter of chamfer, *i.e.*, ·510″ − (·010″ × 2) = ·490″.

Mathematically, the problem would be written :—

$$2\,(\cdot 008'' \pm \cdot 002'') = \cdot 016'' \pm \cdot 004''$$

$$\begin{array}{r} \cdot 500'' \pm \cdot 010'' \\ \cdot 016'' \pm \cdot 004'' \\ \hline \cdot 516'' \pm \cdot 006'' \\ \hline\hline \end{array}$$

Rule 14.—The tolerance on the rough diameter of a 90° countersink or a 45° chamfer, is the finished tolerance *minus twice* the tolerance on the amount removed from the face.

Fig. 15 shows a 60° centre with a finished diameter of $\cdot500'' \pm\cdot010''$. The face is to be ground at a later operation, so it is necessary to know the tolerance on the rough diameter. $\cdot008'' \pm\cdot002''$ is the amount to be removed, therefore, as shown in previous examples, the mean figure of the rough diameter of the chamfer will be $\cdot509238''$ or $\cdot509\frac{1}{4}''$ approximately, *i.e.*, $\cdot500'' + (2 \times \cdot008'' \times \tan 30^\circ)$. The tolerance will be $\cdot007690''$ or $\cdot007\frac{11}{16}''$ approximately, *i.e.*, $\cdot010'' - (2 \times \cdot002'' \times \tan 30^\circ)$. The size of the rough diameter of the chamfer will, therefore, appear on the operation sheet as $\cdot502''/\cdot516''$.

Proof is supplied by the following :—

The greatest rough diameter of the chamfer, minus twice the smallest amount removed from the face times the tangent of 30°, equals the greatest finished diameter, *i.e.*, $\cdot516'' - (2 \times \cdot006'' \times \tan 30^\circ) = \cdot509\frac{1}{16}''$ approx. The smallest rough diameter of the chamfer, minus twice the greatest amount removed from the face times the tangent of 30°, equals the smallest finished diameter, *i.e.*, $\cdot502'' - (2 \times \cdot010'' \times \tan\ 30^\circ) = \cdot490\frac{7}{16}''$ approx. The slight variation between the "finished part drawing" size $(\cdot490''/\cdot510'')$ and the achieved finished size $(\cdot490\frac{7}{16}''/\cdot509\frac{1}{16}'')$ is, as explained in previous examples, the result of approximating the calculations, but the latter comes within the former and it is the nearest it is practical to achieve.

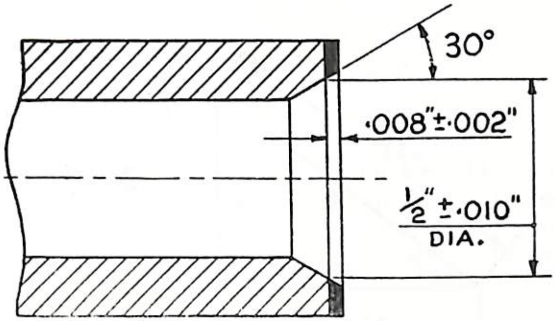


Fig. 15.

Mathematically, the problem would be written :—

$$\begin{array}{l} 2 \times \cdot008'' \times \tan 30^\circ = \cdot009\frac{1}{4}'' \text{ approx.} \\ 2 \times \cdot002'' \times \tan 30^\circ = \cdot002\frac{5}{16}'' \text{ approx.} \end{array}$$

$$\begin{array}{rl} \cdot500'' & \pm \cdot010'' \\ \cdot009\frac{1}{4}'' & \pm \cdot002\frac{5}{16}'' \\ \hline \cdot509\frac{1}{4}'' & \pm \cdot007\frac{11}{16}'' \\ \hline \end{array}$$

Rule 15.—The tolerance on the rough diameter of a chamfer at other than 45° is the finished tolerance, *minus twice* the tolerance on the amount removed from the face times the tangent of the angle.

The final rule in this thesis concerns the tolerances on sides of a triangle.

Fig. 16 shows a triangle with sides A, B and C, the lengths of which are ·500″, ·400″ and ·300″ respectively.

To *achieve* the tolerance on side A as ± ·010″, the tolerance on side B must be ± ·008″, *i.e.*, $\frac{\cdot400'' \times \cdot010''}{\cdot500''}$, or the tolerance on side C must be ± ·006″, *i.e.*, $\frac{\cdot300'' \times \cdot010''}{\cdot500''}$.

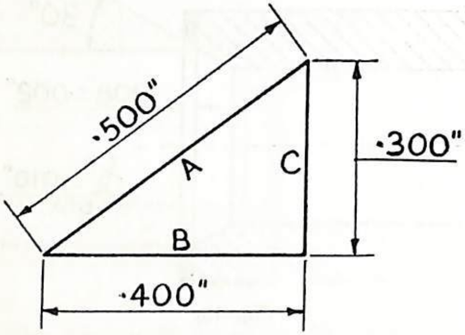


Fig. 16.

This statement can be proved by applying the following geometrical fact. When the angles in a triangle are equal to the angles of another triangle, the triangles are similar and their corresponding sides are proportional.

The greatest length of side B is given as ·408″, therefore the greatest length of side A will be ·510″, *i.e.*, $\frac{\cdot408'' \times \cdot500''}{\cdot400''}$.

The shortest length of side B is given as ·392″, therefore the shortest length of side A will be ·490″, *i.e.*, $\frac{\cdot392'' \times \cdot500''}{\cdot400''}$.

The greatest length of side C is ·306″, therefore the greatest length of side A will be ·510″, *i.e.*, $\frac{\cdot306'' \times \cdot500''}{\cdot300''}$.

The shortest length of side C is ·294″, therefore the shortest length of side A will be ·490″, *i.e.*, $\frac{\cdot294'' \times \cdot500''}{\cdot300''}$.

The following statements can be proved by the same method.

To *achieve* the tolerance on side B as ± ·010″, the tolerance on side A must be ±·012½″, *i.e.*, $\frac{\cdot500'' \times \cdot010''}{\cdot400''}$, or the tolerance on side C must be ±·007½″, *i.e.*, $\frac{\cdot300'' \times \cdot010''}{\cdot400''}$.

To *achieve* the tolerance on side C as ± ·010″, the tolerance on side A must be ±·016⅔″, *i,e.*, $\frac{\cdot500'' \times \cdot010''}{\cdot300''}$, or the tolerance on side B must be ±·013⅓″, *i.e.*, $\frac{\cdot400'' \times \cdot010''}{\cdot300''}$.

Mathematically, the problems would be written as shown in the examples.

Rule 16.—To *achieve* the tolerance on any side of a triangle, the tolerance on the side *given* must be in the same proportion to the tolerance *to be achieved*, as the mean figure *given* is to the mean figure of the side *to be achieved*. This rule applies to *any* triangle, whether right angle or otherwise.

When the foregoing rules have been thoroughly digested, the formulae, given at the end of the book, should be sufficient to solve any "tolerance" problem.

RULE APPLICATION IN PRACTICE.

Once the rules have been mastered, the dimensioning of operation sheets should be fairly straightforward, but a few examples showing the dimensioning of a series of sheets, which will produce a finished part, should make the whole process clear.

The following sketches are not intended to be well designed from an engineering point of view, but have been drawn with the sole object of explaining tolerances.

The finished part shown in Fig. 17 has to be achieved in five operations, and the layout reads as follows :—

Operation 1.—Face end face, turn to ·887″/·891″ diameter and face flange, leaving ·007″ for grinding. Turn flange diameter to 1·505″/1·507″, chamfer at 45° and 30°. Form recess. Drill and ream ·439″/·442″ diameter and bore ·495″/·505″ diameter to depth. Part off plus $\frac{1}{64}$″.

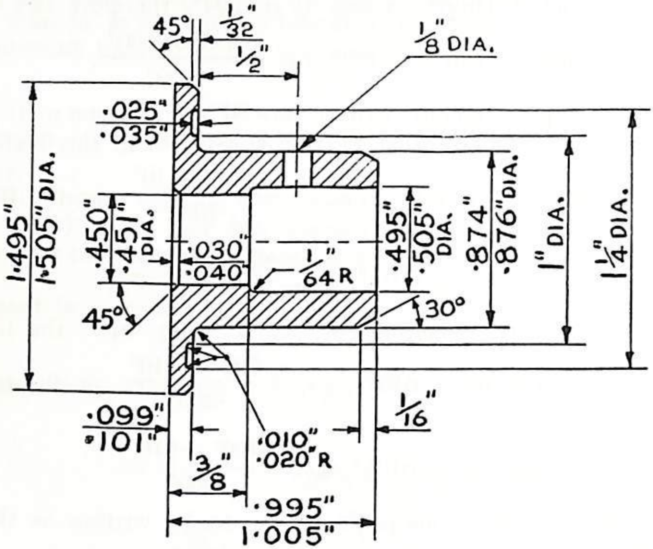


Fig. 17.

Operation 2.—Face flange to ·105″/·109″ and chamfer bore at 45°.

Operation 3.—Drill $\frac{1}{8}''$ diameter hole through one side only.

Operation 4.—Grind bore to ·450″/·451″ diameter.

Operation 5.—Grind 1·495″/1·505″ and ·874″/·876″ diameters and flange face.

The operation sheets would be dimensioned, as shown in Figs. 18 to 22, and the following text explains how the figures shown have been calculated. All fractional figures are allowed a tolerance of ± ·010″.

Operation 1 (Fig. 18).

The finished overall length of 1·000″ ± ·005″ must be achieved, therefore as the width of the flange in Operation 2 is to be ·107″ ±·002″, the length from the small end face to the flange face must be given as ·893″ ± ·003″. (Rule 1).

$$\begin{array}{r} 1{\cdot}000'' \pm {\cdot}005'' \\ {\cdot}107'' \pm {\cdot}002'' \\ \hline {\cdot}893'' \pm {\cdot}003'' \\ \hline\hline \end{array}$$

The finished length of the ·450″ diameter bore must be achieved as ·375″ ± ·010″, therefore, as the overall length will be 1·000″ ±·005″, the depth of the $\frac{1}{2}''$ diameter bore must be given as ·625″ ±·005″. (Rule 1).

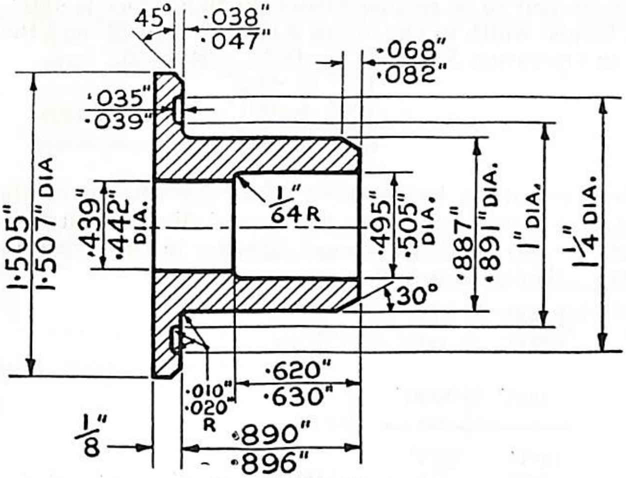


Fig. 18 (Op. 1).

1·000″ ± ·005″
·375″ ± ·010″

·625″ ± ·005″

The amount to be removed from the surface of the small diameter is ·007″ ± ·001½″ as the turned diameter in Operation 1 is ·889″ ± ·002″ and the ground diameter in Operation 5 is ·875″ ± ·001″. (Rule 5).

·889″ ± ·002″
·875″ ± ·001″

·014″ ± ·003″

$$\frac{\cdot014'' \pm \cdot003''}{2} = \cdot007'' \pm \cdot001\tfrac{1}{2}''$$

The finished depth of the 30° chamfer must be achieved as ·062½″ ± ·010″. The amount removed from the diameter will lengthen this dimension by approximately ·012⅛″ ± ·002⅝″, *i.e.*, ·007″ ± ·001½″ × cot 30°, therefore the turned depth of the chamfer must be given as ·074⅝″ ± ·007⅜″ or ·068″/·082″. (Rule 11).

·007″ × cot 30° = ·012⅛″ approx.
·001½″ × cot 30° = ·002⅝″ approx.
·062½″ ± ·010″
·012⅛″ ± ·002⅝″

·074⅝″ ± ·007⅜″ = ·067¼″/·082″ or ·068″/·082″ approx.

The amount to be removed from the flange face is ·007″ ± ·003″ as the turned width in Operation 2 is ·107″ ± ·002″ and the ground width in Operation 5 is ·100″ ± ·001″. (Rule 2).

$$\begin{array}{l} \cdot107'' \pm \cdot002'' \\ \underline{\cdot100'' \pm \cdot001''} \\ \underline{\underline{\cdot007'' \pm \cdot003''}} \end{array}$$

The amount to be removed from the surface of the flange diameter is ·004″ ± ·002″, as the turned diameter in Operation 1 is 1·506″ ± ·001″ and the ground diameter in Operation 5 is 1·500″ ± ·005″. (Rules 5 and 6).

$$\begin{array}{l} 1{\cdot}506'' \pm \cdot001'' \\ \underline{1{\cdot}500'' \pm \cdot005''} \\ \underline{\underline{\cdot006'' \pm \cdot006''}} \end{array} \qquad \frac{\cdot006'' \pm \cdot006''}{2} = \cdot003'' \pm \cdot003''$$

$$\frac{\cdot003'' + \cdot003''}{2} + \cdot001'' = \cdot004'' \text{ mean figure.}$$

$$\frac{\cdot003'' + \cdot003''}{2} - \cdot001'' = \cdot002'' \text{ tolerance.}$$

For explanation of the last two calculations see "Tolerance and Mean Figure Formulae" at end of book. "Amount removed from the surface of a diameter." (Rule 6).

The finished depth of the 45° chamfer on the flange must be achieved as $\cdot031\frac{1}{4}''$ ± ·010″. The amount to be removed from the face is ·007″ ± ·003″ and the amount to be removed from the surface of the diameter is ·004″ ± ·002″, therefore the turned depth of chamfer must be given as $\cdot042\frac{1}{4}''$ ± ·005″ or ·038″/·047″. (Rules 9 and 10).

$$\begin{array}{l} \cdot031\frac{1}{4}'' \pm \cdot010'' \\ \underline{\cdot007'' \;\; \pm \cdot003''} \\ \cdot038\frac{1}{4}'' \pm \cdot007'' \\ \underline{\cdot004'' \;\; \pm \cdot002''} \\ \underline{\underline{\cdot042\frac{1}{4}'' \pm \cdot005''}} = \cdot037\frac{1}{4}''/\cdot047\frac{1}{4}'' \text{ or } \cdot038''/\cdot047'' \text{ approx.} \end{array}$$

The finished depth of the recess must be achieved as ·030″ ± ·005″. The amount to be removed from the face is ·007″ ± ·003″, therefore the depth of the recess in Operation 1 must be ·037″ ± ·002″. (Rule 7).

$$\begin{array}{l} \cdot030'' \pm \cdot005'' \\ \underline{\cdot007'' \pm \cdot003''} \\ \underline{\underline{\cdot037'' \pm \cdot002''}} \end{array}$$

If the latter calculation is reversed, Rule 8 is proved as follows :—

·037″ ± ·002″ turned size.
·007″ ± ·003″ to be removed.

·030″ ± ·005″ finished size achieved.

Operation 2. (Fig. 19).

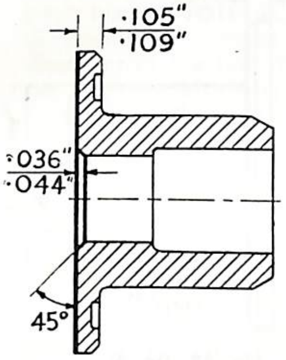


Fig. 19 (Op. 2).

The amount to be removed from the surface of the bore is ·005″ ± ·001″ as the reamed diameter in Operation 1 is ·440½″ ± ·001½″ and the ground diameter in Operation 4 is ·450½″ ± ·000½″. (Rule 5).

·450½″ ± ·000½″
·440½″ ± ·001½″

·010″ ± ·002″

$$\frac{\cdot010'' \pm \cdot002''}{2} = \cdot005'' \pm \cdot001''$$

The finished depth of the 45° chamfer in the bore must be achieved as ·035″ ± ·005″. The amount to be removed from the surface of the bore is ·005″ ± ·001″, therefore the turned depth of chamfer must be given as ·040″ ± ·004″. (Rule 10).

·035″ ± ·005″
·005″ ± ·001″

·040″ ± ·004″

Operation 3. (Fig. 20).

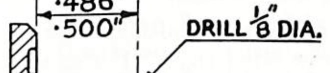


Fig. 20 (Op. 3)

The finished position of the ⅛″ diameter hole must be achieved as ·500″ ± ·010″ from the flange face. The amount to be removed from this face is ·007″ ± ·003″, therefore the position of the hole in Operation 3 must be ·493″ ±·007″ from the flange face. (Rule 7).

·500″ ± ·010″
·007″ ± ·003″

·493″ ± ·007″

If this calculation is reversed, Rule 8 is proved as follows :—

·493″ ± ·007″ position at Operation 3.
·007″ ± ·003″ to be removed.

·500″ ± ·010″ finished position achieved.

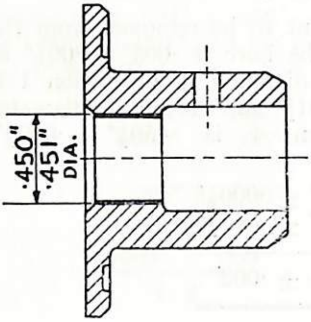


Fig. 21 (**Op. 4**).

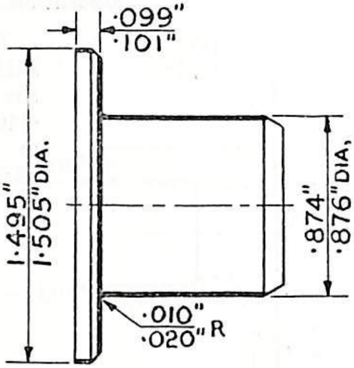


Fig. 22 (**Op. 5**).

Operation 4. (Fig. 21).

By grinding the bore to ·450$\frac{1}{2}$″ ± ·000$\frac{1}{2}$″ diameter, the ·035″ ± ·005″ × 45° chamfer is achieved.

Operation 5. (Fig. 22).

By grinding the small diameter to ·875″ ± ·001″ the $\frac{1}{16}$″ ± ·010″ × 30° chamfer is achieved. By grinding the flange diameter to 1·500″ ± ·005″, and the flange face to ·100″ ± ·001″ wide, the $\frac{1}{32}$″ ± ·010″ × 45° chamfer is achieved. The depth of the recess, ·030″ ± ·005″, and the position of the $\frac{1}{8}$″ diameter hole are also achieved by grinding the flange face.

It is opportune to mention that sometimes finished sizes have to be "tightened up" in order to achieve other sizes. For example, if the overall length had been allowed a tolerance of ± ·010″, the full tolerance could not be used, as the length of the ·450″ bore must finish within the same tolerance. It must be remembered that any achieved size has a tolerance which is equal to the sum of the tolerances of the dimensions used to achieve that size.

In Operation 1 the $\frac{1}{16}$″ ± ·010″ × 30° chamfer could have been given as a diameter, and it would therefore be unnecessary to determine the amount being removed from the surface of the small diameter. The finished outside diameter is ·875″ ± ·001″, therefore the diameter of the chamfer, which will achieve the depth stated, would be given as ·802$\frac{13}{16}$″ ± ·010$\frac{9}{16}$″ or ·793″/·813″. (Rule 13).

$$\begin{array}{l} \quad 2\,(\cdot062\tfrac{1}{2}'' \times \tan 30^\circ) = \cdot072\tfrac{3}{16}'' \text{ approx.} \\ \quad 2\,(\cdot010'' \quad \times \tan 30^\circ) = \cdot011\tfrac{9}{16}'' \text{ approx.} \\ \cdot875'' \quad \pm \cdot001'' \\ \cdot072\tfrac{3}{16}'' \pm \cdot011\tfrac{9}{16}'' \\ \hline \cdot802\tfrac{13}{16}'' \pm \cdot010\tfrac{9}{16}'' = \cdot792\tfrac{1}{4}''/\cdot813\tfrac{3}{8}'' \text{ or } \cdot793''/\cdot813'' \text{ approx.} \end{array}$$

In Operation 2, the ·035″ ± ·005″ × 45° chamfer could also have been given as a diameter, thereby making it unnecessary to determine the amount being removed from the bore. The finished diameter of the bore is $\cdot450\tfrac{1}{2}''$ ± $\cdot000\tfrac{1}{2}''$, therefore the diameter of the chamfer which will achieve the stated depth would be $\cdot520\tfrac{1}{2}''$ ± $\cdot009\tfrac{1}{2}''$. (Rule 12).

$$\begin{array}{l} 2\,(\cdot035'' \pm \cdot005'') = \cdot070'' \pm \cdot010'' \\ \cdot450\tfrac{1}{2}'' \pm \cdot000\tfrac{1}{2}'' \\ \cdot070'' \quad \pm \cdot010'' \\ \hline \cdot520\tfrac{1}{2}'' \pm \cdot009\tfrac{1}{2}'' \end{array}$$

Whether depth or diameter of chamfer is to be given is the jig and tool department's decision, depending on the design of tools and gauges. Usually a depth is given unless otherwise requested.

The finished part shown in Fig. 23 has to be achieved in five operations, and the layout reads as follows :—

Operation 1.—Turn outside diameter to 1·510″/ 1·520″, and face small end face. Turn $\tfrac{7}{8}''$ diameter, form $1\tfrac{1}{4}''$ diameter recess, face to ·241″/·243″ from end face and chamfer at 45° and 15°. Drill and ream ·448″/·450″ diameter, counterbore $\tfrac{5}{8}''$ diameter by ·054″/·056″ deep and chamfer bore at 30°. Part off plus $\tfrac{1}{32}''$.

Operation 2.—Face to overall width, chamfer outside diameter at 45° and chamfer bore at 30°.

Operation 3.—Grind bore to ·460″/·462″ diameter.

Operation 4.—Grind face to ·061″/·063″.

Operation 5.—Grind face to ·249″/·251″.

The operation sheets would be dimensioned, as shown in Figs. 24 to 28, and the following text explains how the figures shown have been calculated. All fractional figures are allowed a tolerance of ± ·010″.

Operation 1. (Fig. 24).

The amount to be removed from the large face by grinding is ·008″ ± ·002″, as the turned dimension in Operation 1 is ·242″ ± ·001″ and the "ground" dimension in Operation 5 is ·250″ ± ·001″. (Rule 2).

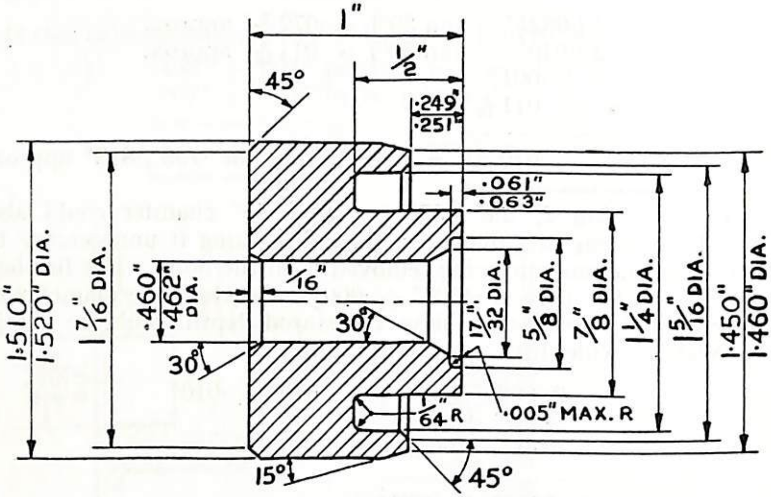


Fig. 23.

·250″ ± ·001″
·242″ ± ·001″
·008″ ± ·002″

The finished diameter of the 45° chamfer must be achieved as 1·312½″ ± ·010″ The amount to be removed from the face is ·008″ ± ·002″ and this will affect the diameter by ·016″ ± ·004″, therefore the diameter of the chamfer at Operation 1 must be given as 1·328½″ ± ·006″ or 1·323″/1·334″. (Rule 14).

2 (·008″ ± ·002″) = ·016″ ± ·004″
1·312½″ ± ·010″
·016″ ± ·004″
1·328½″ ± ·006″ = 1·322½″/1·334½″ or 1·323″/1·334″ approx.

The finished diameter of the 15° chamfer must be achieved as 1·455″ ± ·005″. The amount to be removed from the face is ·008″ ±·002″ and this will affect the diameter by approximately ·004$\frac{5}{16}$″ ±·001$\frac{1}{16}$″, *i.e.*, 2 (·008″ ± ·002″ × tan 15°), therefore the diameter of the chamfer at Operation 1 must be given as 1·450$\frac{11}{16}$″ ± ·003$\frac{15}{16}$″ or 1·447″/1·454″. (Rule 15).

2 (·008″ × tan 15°) = ·004$\frac{5}{16}$″ approx.
2 (·002″ × tan 15°) = ·001$\frac{1}{16}$″ approx.
1·455″ ±·005″
·004$\frac{5}{16}$″ ±·001$\frac{1}{16}$″
1·450$\frac{11}{16}$″ ±·003$\frac{15}{16}$″ = 1·446¾″/1·454⅝″ or 1·447″/1·454″ approx.

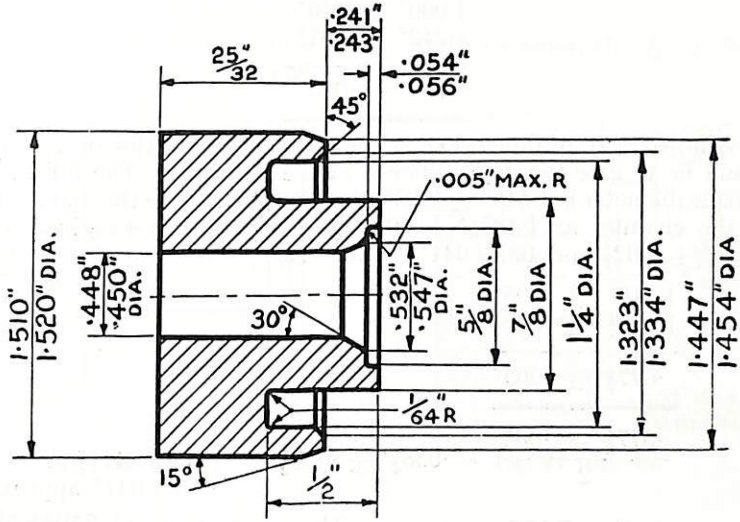


Fig. 24 (Op. 1).

The amount to be removed from the counterbore face is ·007″ ±·002″ as the turned depth in Operation 1 is ·055″ ± ·001″ and the "ground" depth in Operation 4 is ·062″ ± ·001″. (Rule 2).

$$\begin{array}{r} \cdot 062'' \pm \cdot 001'' \\ \cdot 055'' \pm \cdot 001'' \\ \hline \cdot 007'' \pm \cdot 002'' \end{array}$$

The finished diameter of the 30° chamfer must be achieved as $\cdot 531\frac{1}{4}'' \pm \cdot 010''$. The amount to be removed from the face is ·007″ ±·002″ and this will affect the diameter by $\cdot 008\frac{1}{16}'' \pm \cdot 002\frac{5}{16}''$, *i.e.*, 2 (·007″ ± ·002″ × tan 30°), therefore the diameter of the chamfer at Operation 1 must be given as $\cdot 539\frac{5}{16}'' \pm \cdot 007\frac{11}{16}''$ or ·532″/·547″. (Rule 15).

$$2\,(\cdot 007'' \times \tan 30^\circ) = \cdot 008\tfrac{1}{16}'' \text{ approx.}$$
$$2\,(\cdot 002'' \times \tan 30^\circ) = \cdot 002\tfrac{5}{16}'' \text{ approx.}$$

$$\begin{array}{l} \cdot 531\frac{1}{4}'' \pm \cdot 010'' \\ \cdot 008\frac{1}{16}'' \pm \cdot 002\frac{5}{16}'' \\ \hline \cdot 539\frac{5}{16}'' \pm \cdot 007\frac{11}{16}'' = \cdot 531\frac{5}{8}''/\cdot 547'' \text{ or } \cdot 532''/\cdot 547'' \text{ approx.} \end{array}$$

Operation 2. (Fig. 25).

The finished overall width of 1·000″ ± ·010″ must be achieved, therefore as the dimension from the small end face to the recessed face in Operation 1 is ·242″ ± ·001″, the dimension from the recessed face in Operation 2 must be given as ·758″ ± ·009″. (Rule 1).

$$\begin{array}{r}1{\cdot}000'' \pm {\cdot}010'' \\ {\cdot}242'' \pm {\cdot}001'' \\ \hline {\cdot}758'' \pm {\cdot}009'' \\ \hline\hline\end{array}$$

Another way of dimensioning the 45° chamfer in this operation would be to give the depth instead of the diameter. The finished outside diameter is $1{\cdot}515'' \pm {\cdot}005''$, therefore to achieve the diameter of the chamfer as $1{\cdot}437\frac{1}{2}'' \pm {\cdot}010''$, the depth must be given as ${\cdot}038\frac{3}{4}'' \pm {\cdot}002\frac{1}{2}''$ or ·037″/·041″. (Rule 12).

$$\begin{array}{l}1{\cdot}515'' \pm {\cdot}005'' \\ 1{\cdot}437\frac{1}{2}'' \pm {\cdot}010'' \\ \hline {\cdot}077\frac{1}{2}'' \pm {\cdot}005'' \\ \hline\hline\end{array}$$

$$\frac{{\cdot}077\frac{1}{2}'' \pm {\cdot}005''}{2} = {\cdot}038\frac{3}{4}'' \pm {\cdot}002\frac{1}{2}'' = {\cdot}036\frac{1}{4}''/{\cdot}041\frac{1}{4}'' \text{ or } {\cdot}037''/{\cdot}041'' \text{ approx.}$$

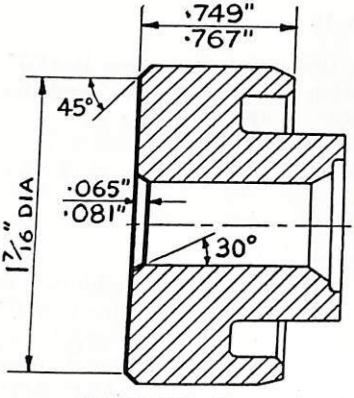


Fig. 25 (Op. 2).

The amount to be removed from the surface of the bore is $\cdot006'' \pm \cdot001''$ as the reamed diameter in Operation 1 is $\cdot449'' \pm \cdot001''$ and the ground diameter in Operation 3 is $\cdot461'' \pm \cdot001''$. (Rule 5).

$$\begin{array}{r}{\cdot}461'' \pm {\cdot}001'' \\ {\cdot}449'' \pm {\cdot}001'' \\ \hline {\cdot}012'' \pm {\cdot}002'' \\ \hline\hline\end{array}$$

$$\frac{{\cdot}012'' \pm {\cdot}002''}{2} = {\cdot}006'' \pm {\cdot}001''$$

The finished depth of the 30° chamfer on the plain face must be achieved as ${\cdot}062\frac{1}{2}'' \pm {\cdot}010''$. The amount removed from the surface of the bore in Operation 3 is $\cdot006'' \pm \cdot001''$ and this will affect the depth by approximately ${\cdot}010\frac{3}{8}'' \pm {\cdot}001\frac{3}{4}''$, *i.e.*, $\cdot006'' \pm \cdot001'' \times \cot 30°$, therefore the turned depth of the chamfer must be given as ${\cdot}072\frac{7}{8}'' \pm {\cdot}008\frac{1}{4}''$ or ·065″/·081″. (Rule 11).

$$\begin{array}{l}{\cdot}006'' \times \cot 30° = {\cdot}010\frac{3}{8}'' \text{ approx.} \\ {\cdot}001'' \times \cot 30° = {\cdot}001\frac{3}{4}'' \text{ approx.} \\ {\cdot}062\frac{1}{2}'' \pm {\cdot}010'' \\ {\cdot}010\frac{3}{8}'' \pm {\cdot}001\frac{3}{4}'' \\ \hline {\cdot}072\frac{7}{8}'' \pm {\cdot}008\frac{1}{4}'' = {\cdot}064\frac{5}{8}''/{\cdot}081\frac{1}{8}'' \text{ or } {\cdot}065''/{\cdot}081'' \text{ approx.}\end{array}$$

Operation 3. (Fig. 26).

By grinding the bore to ·461″ ± ·001″ diameter, the $\frac{1}{16}''$ ± ·010″ × 30° chamfer is achieved.

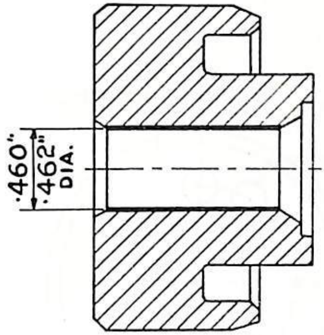


Fig. 26 (Op. 3).

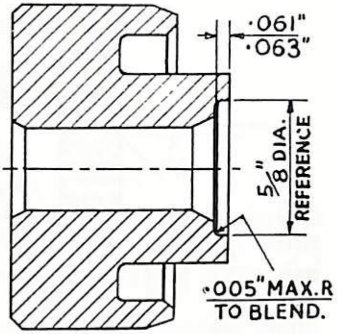


Fig. 27 (Op. 4).

Operation 4. (Fig. 27).

By grinding the counterbore face to ·062″ ± ·001″ the $\frac{17}{32}''$ ± ·010″ diameter × 30° chamfer is achieved.

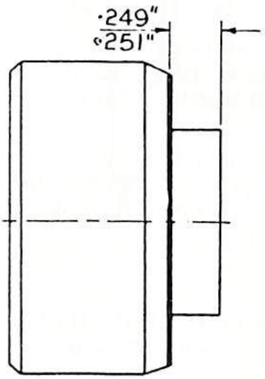


Fig. 28 (Op. 5).

Operation 5. (Fig. 28).

By grinding the recessed face to ·250″ ± ·001″ the 1·455″ ±·005″ diameter × 15° chamfer and the $1\frac{5}{16}''$ ±·010″ diameter × 45° chamfer are achieved.

In Operation 2 the $\frac{1}{16}''$ ± ·010″ × 30° chamfer could have been given as a diameter, thereby making it unnecessary to determine the amount being removed from the surface of the bore. The finished diameter of the bore is ·461″ ± ·001″, therefore the diameter of the chamfer which will achieve the stated depth would be given as $\cdot 533\frac{3}{16}'' \pm \cdot 010\frac{9}{16}''$ or ·523″/·543″. (Rule 13).

$$
\begin{aligned}
2\,(\cdot 062\tfrac{1}{2}'' \times \tan 30^\circ) &= \cdot 072\tfrac{3}{16}'' \text{ approx.}\\
2\,(\cdot 010'' \times \tan 30^\circ) &= \cdot 011\tfrac{9}{16}'' \text{ approx.}
\end{aligned}
$$

$$
\begin{array}{l}
\cdot 461'' \pm \cdot 001'' \\
\underline{\cdot 072\tfrac{3}{16}'' \pm \cdot 011\tfrac{9}{16}''} \\
\underline{\underline{\cdot 533\tfrac{3}{16}'' \pm \cdot 010\tfrac{9}{16}''}} = \cdot 522\tfrac{5}{8}''/\cdot 543\tfrac{3}{4}'' \text{ or } \cdot 523''/\cdot 543'' \text{ approx.}
\end{array}
$$

The finished part, shown in Fig. 29, has to be achieved in four operations, and the layout reads as follows :—

Operation 1.—Turn outside diameter to 1·348″/1·352″, face and chamfer outside diameter at 45°. Drill and ream ·400″/·404″ and chamfer bore at 45°. Part off plus $\frac{1}{64}$″.

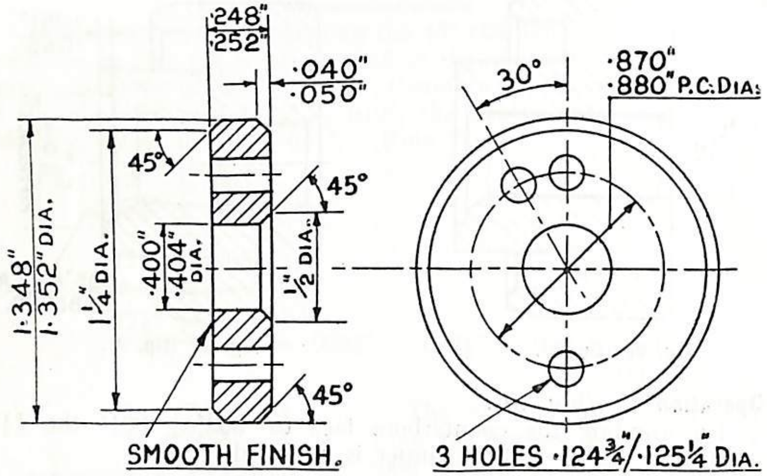


Fig. 29.

Operation 2.—Face to ·250″/·254″ wide and chamfer at 45°.

Operation 3.—Drill and ream three holes, ·124$\frac{3}{4}$″/·125$\frac{1}{4}$″ diam.

Operation 4.—Skim grind face to overall width. (Note smooth finish).

The Operation Sheets would be dimensioned, as shown in Figs. 30 to 33, and the following text explains how the figures shown have been calculated. All fractional figures are allowed a tolerance of ± ·010″.

Operation 1. (Fig. 30).

The dimensioning of this operation is quite straightforward, all dimensions given being finished sizes except, of course, the parting off dimension.

Another way of dimensioning the ½″ diameter × 45° chamfer in this operation would be to give depth instead of the diameter. The finished diameter of the bore is ·402″ ±·002″, therefore to achieve the diameter of the chamfer as ·500″ ± ·010″, the depth must be given as ·049″ ± ·004″. (Rule 12).

$$\begin{array}{l} \cdot500'' \pm \cdot010'' \\ \cdot402'' \pm \cdot002'' \\ \hline \cdot098'' \pm \cdot008'' \\ \hline\hline \end{array} \qquad \frac{\cdot098'' \pm \cdot008''}{2} = \cdot049'' \pm \cdot004''.$$

The ·045″ × 45° chamfer could be given as a diameter instead of as a depth. The finished outside diameter is 1·350″ ± ·002″, therefore to achieve the depth of the chamfer as ·045″ ± ·005″, the diameter must be given as 1·260″ ± ·008″. (Rule 12).

$$2\,(\cdot045'' \pm \cdot005'') = \cdot090'' \pm \cdot010''$$

$$\begin{array}{r} 1\cdot350'' \pm \cdot002'' \\ \cdot090'' \pm \cdot010'' \\ \hline 1\cdot260'' \pm \cdot008'' \\ \hline\hline \end{array}$$

It is opportune to mention that jig and tool draughtsmen will find Rule 12 very useful for the gauging of 45° chamfers, where it is usually necessary to give a diameter to achieve a depth.

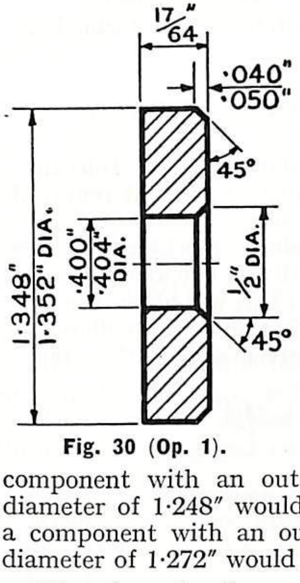


Fig. 30 (Op. 1).

This raises a rather interesting point. According to the "finished part drawing" the component should pass inspection if the outside diameter is 1·348″ and the diameter of the chamfer is 1·248″, because this gives the depth of chamfer as ·050″. Similarly, if the outside diameter is 1·352″ and the diameter of the chamfer is 1·272″, this should also pass inspection as the depth of chamfer is ·040″.

At first glance it would appear that the chamfer diameter gauge should be made 1·248″/1·272″, but this is not so, because it would be possible for scrap components to get past inspection. For example, a component with an outside diameter of 1·352″ and a chamfer diameter of 1·248″ would give the depth of chamfer as ·052″ and a component with an outside diameter of 1·348″ and a chamfer diameter of 1·272″ would give a depth of ·038″.

Therefore, in the correct application of "tolerances" under certain conditions, components on the "high" or "low" limits and which would pass inspection, are excluded, otherwise a number of scrap parts would be produced and passed by inspection.

This problem can be solved in a number of ways. The design department may agree to give a diameter instead of a depth on the finished part drawing, or the jig and tool department may agree to gauge the depth instead of the diameter. Failing either of these a re-inspection could take place where exact measurements are made. The problem applies not only to chamfers but to recesses, widths and lengths, etc., and is one of the consequences of mass production.

Operation 2. (Fig. 31).

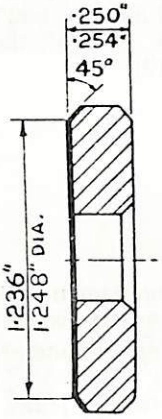


Fig. 31 (Op. 2).

The face machined in this operation is to be ground in Operation 4. Using Rule 2, ·002″ ± ·004″ is found to be the amount to be removed, as the turned width is ·252″ ± ·002″ and the finished "ground" width is ·250″ ± ·002″. Using Rule 3, ·002″ ± ·004″ in theory becomes ·004 ± ·002″ in practice.

$$\begin{array}{l} \cdot 252'' \pm \cdot 002'' \\ \cdot 250'' \pm \cdot 002'' \\ \hline \cdot 002'' \pm \cdot 004'' \\ \hline\hline \end{array}$$

$$\frac{\cdot 002'' + \cdot 004''}{2} + \cdot 001'' = \cdot 004'' \text{ mean fig.}$$

$$\frac{\cdot 002'' + \cdot 004''}{2} - \cdot 001'' = \cdot 002'' \text{ tolerance.}$$

For explanation of the last two calculations, see "Tolerance and Mean Figure Formulae" at end of book. "Amount removed from a face." (Rule 3).

The finished diameter of the 45° chamfer machined in this operation must be achieved as 1·250″ ± ·010″. The amount to be removed from the face is ·004″ ± ·002″ and this will affect the diameter by ·008″ ± ·004″, *i.e.*, 2 (·004″ ± ·002″), therefore the diameter of the chamfer at Operation 2 must be given as 1·242″ ± ·006″. (Rule 14).

$$2\,(\cdot 004'' \pm \cdot 002'') = \cdot 008'' \pm \cdot 004''$$

$$\begin{array}{r} 1{\cdot}250'' \pm \cdot 010'' \\ \cdot 008'' \pm \cdot 004'' \\ \hline 1{\cdot}242'' \pm \cdot 006'' \\ \hline\hline \end{array}$$

Operation 3. (Fig. 32).

If it were necessary, the hole at 30° to the centre line could be dimensioned from either of the centre lines instead of being on a pitch circle diameter.

To achieve the ·875″ ± ·005″ P.C.D., the distance from the hole to the vertical centre line must be given as ·218¾″ ± ·001¼″ or ·217½/·220″, together with the 30° angle. (Rule 16).

$$\cdot 875'' \pm \cdot 005'' \text{ diameter} = \cdot 437\tfrac{1}{2}'' \pm \cdot 002\tfrac{1}{2}'' \text{ radius.}$$

$$\cdot 437\tfrac{1}{2}'' \times \text{sine } 30^\circ = 218\tfrac{3}{4}'' \text{ mean figure.}$$

$$\cdot 002\tfrac{1}{2}'' \times \text{sine } 30^\circ = \cdot 001\tfrac{1}{4}'' \text{ tolerance ; or}$$

$$\frac{\cdot 002\tfrac{1}{2} \times \cdot 218\tfrac{3}{4}'''}{\cdot 437\tfrac{1}{2}''} = \cdot 001\tfrac{1}{4}'' \text{ tolerance.}$$

To achieve the ·875″ ± ·005″ P.C.D., the distance from the hole to the horizontal centre line must be given as $\cdot 378\frac{7}{8}''$ ± $\cdot 002\frac{1}{8}''$ or $\cdot 376\frac{3}{4}''/\cdot 381''$, together with the 30° angle. (Rule 16).

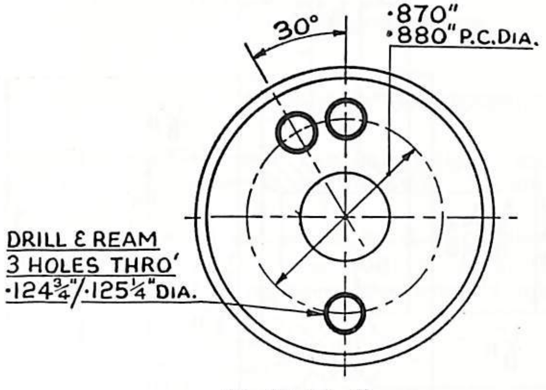


Fig. 32 (Op. 3).

$$\cdot 875'' \pm \cdot 005'' \text{ diameter} = \cdot 437\tfrac{1}{2}'' \pm \cdot 002\tfrac{1}{2}'' \text{ radius.}$$

$$\cdot 437\tfrac{1}{2} \times \text{cosine } 30^\circ = \cdot 378\tfrac{7}{8}'' \text{ mean figure.}$$

$$\cdot 002\tfrac{1}{2}'' \times \text{cosine } 30^\circ = \cdot 002\tfrac{1}{8}'' \text{ tolerance (approx.).}$$

or

$$\frac{\cdot 002\tfrac{1}{2}'' \times \cdot 378\tfrac{7}{8}''}{\cdot 437\tfrac{1}{2}''} = \cdot 002\tfrac{1}{8} \text{ tolerance (approx.).}$$

It is not advisable to dimension from both centre lines instead of using the 30° angle as this would create a tolerance on the angle.

These two examples will be especially interesting to those draughtsmen engaged on designing drill jigs.

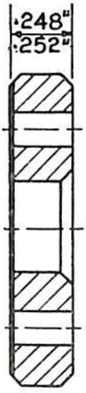


Fig. 33 (Op. 4).

Operation 4. (Fig. 33).

By grinding the face to ·250″ ± ·002″ the 1¼″ ± ·010″ diameter × 45° chamfer is achieved.

The finished part, shown in Fig. 34, has to be achieved in three operations, and the layout reads as follows :—

Operation 1.—Turn to 1¾″ diameter, face (leaving ·004″/·005″ for grinding) form recess, face and chamfer boss at 30°. Drill and ream ·498″/·502″ and chamfer bore at 30°. Part off plus $\frac{1}{32}$″.

Operation 2.—Face to 1·008″/1·012″ wide, form recess and face boss.

Operation 3.—Grind outside faces to 1·000″/1·002″.

The operation sheets would be dimensioned, as shown in Figs. 35 to 37, and the following text explains how the figures shown have been calculated. All fractional figures are allowed a tolerance of ± ·010″.

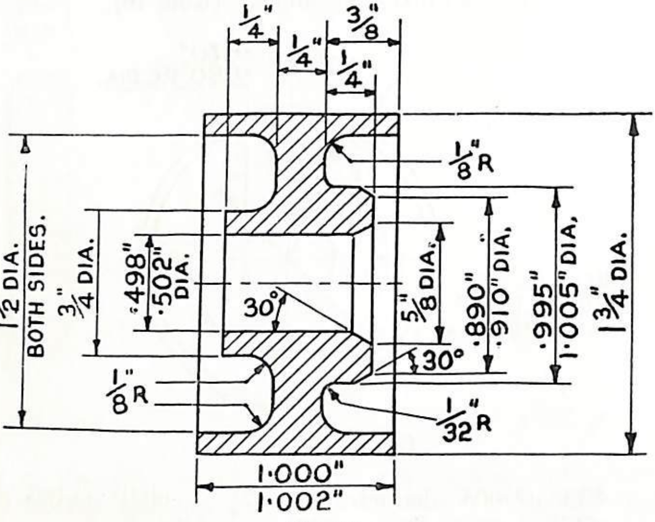


Fig. 34.

Operation 1. (Fig. 35).

The amount to be removed from either of the outside faces is ·006″ ± ·004″, as the turned width in Operation 2 is 1·010″ ± ·002″ and "ground" width in Operation 3 is 1·001″ ± ·001″.

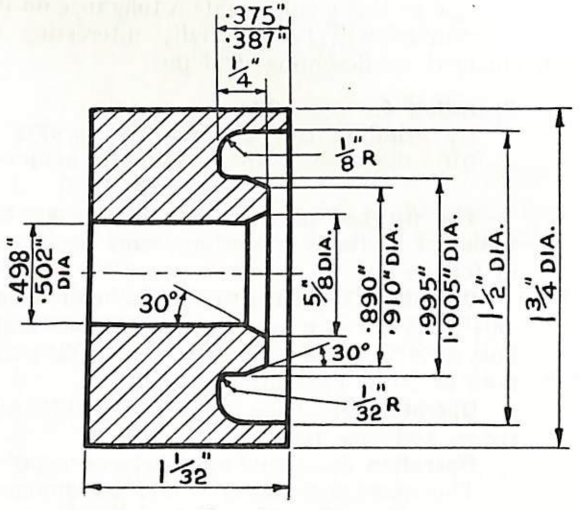


Fig. 35 (Op. 1).

As both faces are touched in the same operation and the grinding dimension given is not tied to a fixed face, this problem is solved by Rule 4.

$$\frac{1{\cdot}012'' - 1{\cdot}000''}{2} = {\cdot}006'' \text{ mean figure.}$$

$$\frac{1{\cdot}012'' - 1{\cdot}000''}{2} - {\cdot}002'' = {\cdot}004'' \text{ tolerance.}$$

For explanation of the last two calculations, see "Tolerance and Mean Figure Formulae" at end of book. "Amount removed from either of two faces." (Rule 4).

The finished depth of the recess must be achieved as ·375″ ± ·010″. The amount to be removed from the face is ·006″ ± ·004″, therefore the depth of the recess in Operation 1 must be ·381″ ± ·006″. (Rule 7).

$$\begin{array}{c} {\cdot}375'' \pm {\cdot}010'' \\ {\cdot}006'' \pm {\cdot}004'' \\ \hline {\cdot}381'' \pm {\cdot}006'' \\ \hline\hline \end{array}$$

The $\frac{5}{8}''$ diameter × 30° chamfer could be given as a depth. The finished bore is ·500″ ± ·002″ diameter, therefore to achieve the diameter of the chamfer as ·625″ ± ·010″, the depth must be given as ${\cdot}108\frac{1}{4}'' \pm {\cdot}006\frac{15}{16}''$ or ·102″/·115″. (Rule 13).

$$\begin{array}{c} {\cdot}625'' \pm {\cdot}010'' \\ {\cdot}500'' \pm {\cdot}002'' \\ \hline {\cdot}125'' \pm {\cdot}008'' \\ \hline\hline \end{array} \qquad \frac{{\cdot}125'' \pm {\cdot}008''}{2} = {\cdot}062\frac{1}{2}'' \pm {\cdot}004''$$

$${\cdot}062\tfrac{1}{2}'' \times \cot 30^\circ = {\cdot}108\tfrac{1}{4}''.$$
$${\cdot}004'' \times \cot 30^\circ = {\cdot}006\tfrac{15}{16}'' \text{ approx.}$$
$${\cdot}108\tfrac{1}{4}'' \pm {\cdot}006\tfrac{15}{16}'' = {\cdot}101\tfrac{5}{16}''/{\cdot}115\tfrac{3}{16}'' \text{ or } {\cdot}102''/{\cdot}115'' \text{ approx.}$$

The ·900″ diameter × 30° chamfer could also be given as a depth. The finished diameter of the boss is 1·000″ ± ·005″, therefore to achieve the diameter of the chamfer as ·900″ ± ·010″, the depth must be given as ${\cdot}086\frac{5}{8}'' \pm {\cdot}004\frac{3}{8}''$, *i.e.*, ${\cdot}050'' \pm {\cdot}002\frac{1}{2}'' \times \cot 30^\circ$. (Rule 13).

$$\begin{array}{c} 1{\cdot}000'' \pm {\cdot}005'' \\ {\cdot}900'' \pm {\cdot}010'' \\ \hline {\cdot}100'' \pm {\cdot}005'' \\ \hline\hline \end{array} \qquad \frac{{\cdot}100'' \pm {\cdot}005''}{2} = {\cdot}050'' \pm {\cdot}002\frac{1}{2}''$$

$${\cdot}050'' \times \cot 30^\circ = {\cdot}086\tfrac{5}{8}'' \text{ approx.}$$
$${\cdot}002\tfrac{1}{2}'' \times \cot 30^\circ = {\cdot}004\tfrac{3}{8}'' \text{ approx.}$$
$${\cdot}086\tfrac{5}{8}'' \pm {\cdot}004\tfrac{3}{8}'' = {\cdot}082\tfrac{1}{4}''/{\cdot}091'' \text{ or } {\cdot}083''/{\cdot}091'' \text{ approx.}$$

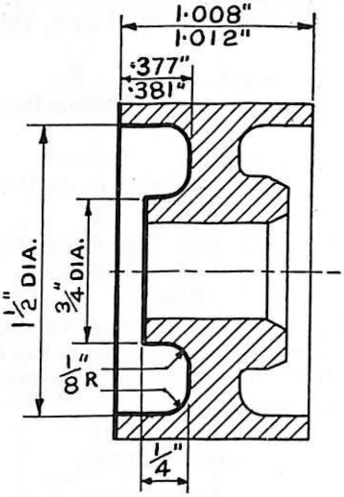


Fig. 36 (Op. 2).

Operation 2. (Fig. 36).

The finished width of metal between the two recesses must be achieved as ·250″ ± ·010″. The overall width in this operation is 1·010″ ± ·002″ and the depth of the recess formed in Operation 1 is ·381″ ± ·006″, therefore the depth of the recess formed in Operation 2 must be given as ·379″ ± ·002″. (Rule 1).

1·010″ ± ·002″
·381″ ± ·006″
·629″ ± ·008″

·629″ ± ·008″
·250″ ± ·010″
·379″ ± ·002″

The dimensioning of the recesses would be improved if both dimensions were given a tolerance of ± ·004″, instead of ± ·006″ in Operation 1 and ± ·002″ in Operation 2.

Proof that the improved dimensioning will achieve the finished part drawing sizes, is as follows :—

The depth of the recess in Operation 1 is to be given as ·381″ ± ·004. The amount to be removed from the face is ·006″ ± ·004″, therefore the finished depth of the recess will be ·375″ ± ·008″, which comes within the "finished part drawing" size of ·375″ ± ·010″. (Rule 8).

·381″ ± ·004″
·006″ ± ·004″
·375″ ± ·008″

The depth of the recess in Operation 2 is to be given as ·379″ ± ·004″. The overall width in this operation is 1·010″ ± ·002″, and the depth of the recess formed in Operation 1 is to be given as ·381″ ± ·004″, therefore the width of metal between the two recesses will be achieved as ·250″ ± ·010″. (Rule 1).

$$\begin{array}{rr} 1{\cdot}010'' \pm {\cdot}002'' & {\cdot}629'' \pm {\cdot}006'' \\ {\cdot}381'' \pm {\cdot}004'' & {\cdot}379'' \pm {\cdot}004'' \\ \hline {\cdot}629'' \pm {\cdot}006'' & {\cdot}250'' \pm {\cdot}010'' \\ \hline\hline \end{array}$$

It is always good practice to share the tolerances as equally as possible between similar machining operations.

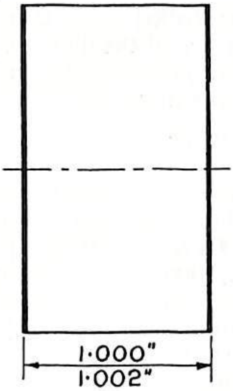


Fig. 37 (Op. 3).

Operation 3. (Fig. 37).

By grinding the outside faces to 1·001″ ± ·001″ the depth of the recess, ·375″ ± ·010″ is achieved.

The final examples of rule application are trigonometrical, as many varied problems will be encountered which can be solved by using Rule 16.

It may be necessary in Fig. 38 to give dimension Z and two "equals" dimensions from the centre of the hexagon, in order to achieve the ·250″ ± ·010″ dimension.

The distance, in a vertical direction, from the centre of the hole to the corner of the hexagon must be given as ·125″ ± ·005″, *i.e.*, ·250″ ± ·010″ × sine 30°. to achieve the ·250″ ± ·010″ dimension. The rest of the problem can now be solved by applying Rule 1. The width of the

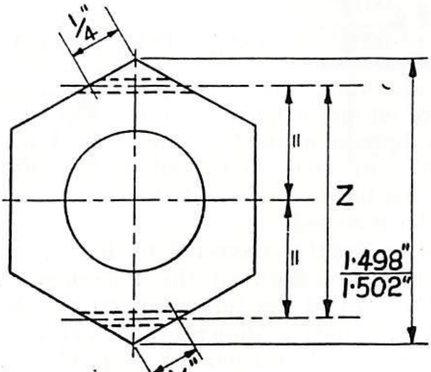


Fig. 38.

hexagon, across the corners, is 1·500" ± ·002", therefore dimension Z must be given as 1·250" ± ·008", together with two "equals" dimensions from the centre of the hexagon, This will achieve the ·125" ± ·005" dimension which in turn will achieve the ·250" ± ·010" dimension.

$$\begin{aligned}
&\cdot 250'' \times \text{sine } 30^\circ = \cdot 125'' \\
&\cdot 010'' \times \text{sine } 30^\circ = \cdot 005'' \\
&2\,(\cdot 125'' \pm \cdot 005'') = \cdot 250'' \pm \cdot 010'' \\
&1{\cdot}500'' \pm \cdot 002'' \\
&\underline{\ \ \cdot 250'' \pm \cdot 010''} \\
&\underline{\underline{1{\cdot}250'' \pm \cdot 008''}}
\end{aligned}$$

The angular hole, shown in Fig, 39, is to be drilled while there is still ·006" ± ·002" to be removed from the surface of the diameter by grinding in a later operation. It is therefore necessary to find the correct position of the hole in the drilling operation.

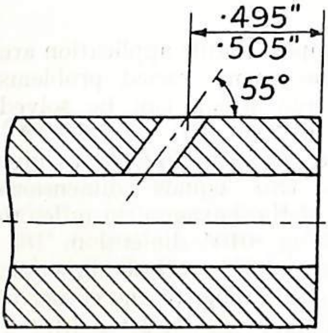


Fig. 39.

The amount to be removed from the surface of the diameter (in a vertical direction) will affect the position of the hole (in a horizontal direction) by $\cdot 004\frac{3}{16}'' \pm \cdot 001\frac{3}{8}''$ approximately, *i.e.*, ·006" ± ·002" × cot 55°, therefore the correct position of the hole when drilled will be $\cdot 495\frac{13}{16}'' \pm \cdot 003\frac{5}{8}''$ or ·493"/·499" approx. from the end face.

$$\cdot 006'' \times \cot 55^\circ = \cdot 004\tfrac{3}{16}'' \text{ approx.}$$
$$\cdot 002'' \times \text{cot. } 55^\circ = \cdot 001\tfrac{3}{8}'' \text{ approx.}$$

$$\begin{aligned}
&\cdot 500'' \pm \cdot 005'' \\
&\underline{\cdot 004\tfrac{3}{16}'' \pm \cdot 001\tfrac{3}{8}''} \\
&\underline{\underline{\cdot 495\tfrac{13}{16}'' \pm \cdot 003\tfrac{5}{8}''}} = 492\tfrac{3}{16}''/\cdot 499\tfrac{7}{16}'' \text{ or } \cdot 493''/\cdot 499'' \text{ approx.}
\end{aligned}$$

Summing up this thesis on "Tolerances," it is possible to state that the tolerance on any achieved size is equal to the sum of the tolerances of the dimensions used to achieve that size.

The tolerance on any rough size should be the difference between the tolerance on the finished size and the sum of the tolerances on the amounts to be removed.

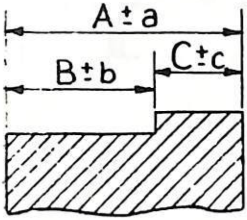
The tolerance on depths converted to diameters, or *vice versa*, should be the difference between the tolerance on the original dimension and the sum of the tolerances on the dimensions used to calculate the alternative dimension. This ensures that the tolerance on the original dimension will be produced.

Tolerances on the sides of triangles should be in the same ratio as the basic lengths of the sides.

TOLERANCE AND MEAN FIGURE FORMULAE.

Any Length.

Required :—The length that is achieved by the addition or substraction of other lengths. (Rule 1).



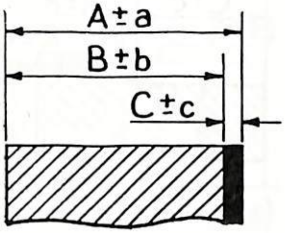
A

Mean Figure : $A = B + C$
$B = A - C$
$C = A - B$

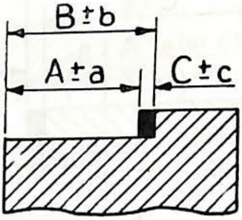
Tolerances : $a = b + c$
$b = a + c$
$c = a + b$

Rough Length.

Required :—The rough length which is to be increased or decreased by an amount removed from a face, and must achieve a stated finished length. (Rule 7).



B



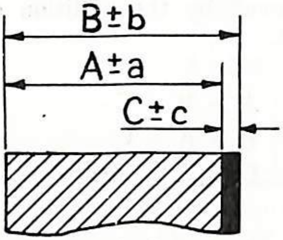
C

Mean Figure : $A = B + C$
Tolerance : $a = b - c$

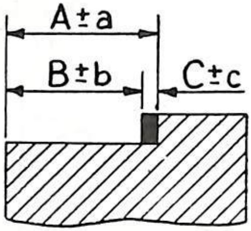
Mean Figure : $A = B - C$
Tolerance : $a = b - c$

Finished Length.

Required :—The finished length achieved, when an amount is removed from a face and increases or decreases a given rough length (Rule 8).



D



E

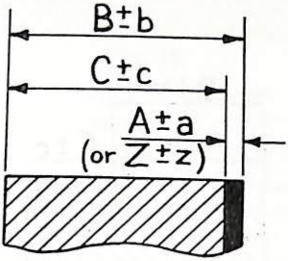
Mean Figure : $A = B - C$
Tolerance : $a = b + c$

Mean Figure : $A = B + C$
Tolerance : $a = b + c$

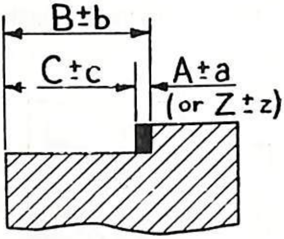
Amount Removed from a Face.

Required :—The amount removed from a face. (Rule 2).

Mean Figure : $A = B - C$
Tolerance : $a = b + c$



F



G

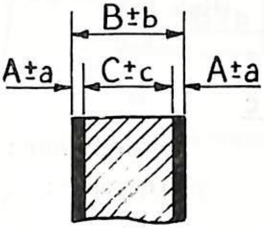
If, after using Rule 2, a is greater than $A - .002''$, convert $A \pm a$ to $Z \pm z$. (Rule 3).

$$\text{Mean Figure : } Z = \frac{A + a}{2} + \cdot 001''$$

$$\text{Tolerance : } z = \frac{A + a}{2} - \cdot 001''$$

Amount Removed from Either of Two Faces.

Required :—The amount removed from either of two faces, when both are touched in the same operation and the dimension given is not tied to a fixed face. (Rule 4).



H

Mean Figure : $$A = \frac{(B + b) - (C - c)}{2}$$

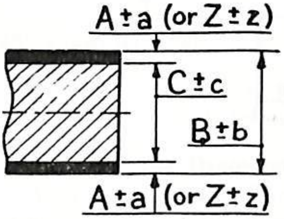
Tolerance : $$a = \frac{(B + b) - (C - c)}{2} - \cdot 002''$$

Amount Removed from the Surface of a Diameter.

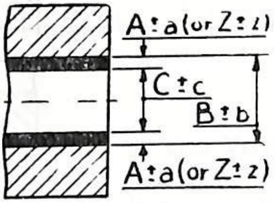
Required :—The amount removed from the surface of a diameter or a bore. (Rule 5).

Mean Figure : $$A = \frac{B - C}{2}$$

Tolerance : $$a = \frac{b + c}{2}$$



I



J

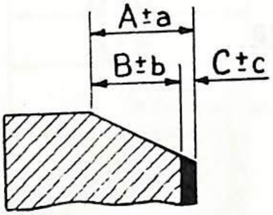
If, after using Rule 5, a is greater than $A - \cdot 002''$, convert $A \pm a$ to $Z \pm z$. (Rule 6).

Mean Figure : $$Z = \frac{A + a}{2} + \cdot 001''$$

Tolerance : $$z = \frac{A + a}{2} - \cdot 001''$$

Rough Depth of Chamfers with an Amount to be Removed from the Face.

Required :—The rough depth of a chamfer which is to be decreased by an amount removed from the face, and must achieve a stated finish depth. (Rule 9).



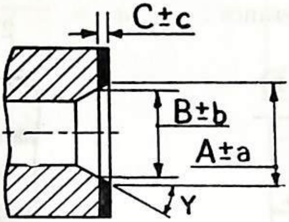
Mean Figure : $A = B + C$
Tolerance : $a = b - c$

K

Rough Diameter of Chamfers with an Amount to be Removed from the Face.

Required :—The rough diameter of a chamfer which is to be decreased by an amount removed from the face, and must achieve a stated finished diameter. (Rule 15).

Mean Figure : $A = B + 2\,(C \times \tan Y)$
Tolerance : $a = b - 2\,(c \times \tan Y)$

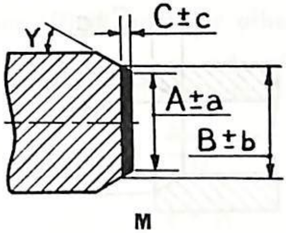


L

45° Chamfers can be solved by the following quicker method :— (Rule 14).

Mean Figure : $A = B + 2C$
Tolerance : $a = b - 2c$

Rule (15). (See diagram M on facing page).
Mean Figure : $A = B - 2\,(C \times \tan Y)$
Tolerance : $a = b - 2\,(c \times \tan Y)$



M

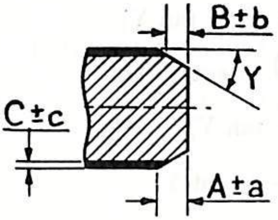
45° Chamfers can be solved by the following quicker method :—
(Rule 14).

Mean Figure : $A = B - 2C$
Tolerance : $a = b - 2c$

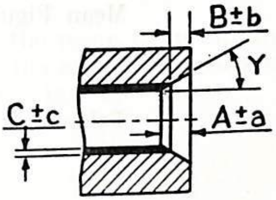
Rough Depth of Chamfers with an Amount to be Removed from the Surface of the Diameter.

Required :—The rough depth of a chamfer which is to be decreased by an amount removed from the surface of the diameter or bore, and must achieve a stated finished depth. (Rule 11).

Mean Figure : $A = B + (C \times \cot Y)$
Tolerance : $a = b - (c \times \cot Y)$



N



O

45° Chamfers can be solved by the following quicker method :—
(Rule 10).

Mean Figure : $A = B + C$
Tolerance : $a = b - c$

To Convert the Diameter of a Chamfer to a Depth or Vice Versa.

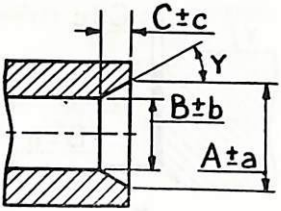
Required :—The diameter of a chamfer that will achieve a stated depth, or the depth of a chamfer that will achieve a stated diameter. (Rule 13). (See diagram P on next page).

Mean Figure : $A = 2\,(C \times \tan Y) + B$

$$C = \frac{A - B}{2} \times \cot Y$$

Tolerance : $a = 2\,(c \times \tan Y) - b$

$$c = \frac{a - b}{2} \times \cot Y$$



P

45° Chamfers can be solved by the following quicker method :—
(Rule 12).

Mean Figure : $A = 2C + B$

$$C = \frac{A - B}{2}$$

Tolerance : $a = 2c - b$

$$c = \frac{a - b}{2}$$

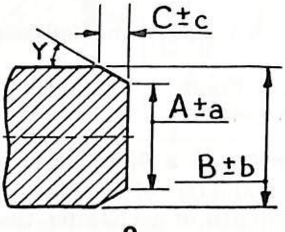
(Rule 13).

Mean Figure : $A = B - 2(C \times \tan Y)$

$$C = \frac{B - A}{2} \times \cot Y$$

Tolerance : $a = 2(c \times \tan Y) - b$

$$c = \frac{a - b}{2} \times \cot Y$$



Q

45° Chamfers can be solved by the following quicker method :—
(Rule 12).

Mean Figure : $A = B - 2C$

$$C = \frac{B - A}{2}$$

Tolerance : $a = 2c - b$

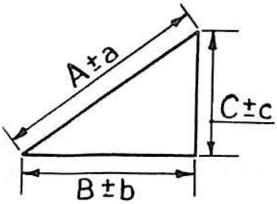
$$c = \frac{a - b}{2}$$

Triangles (Right angle or otherwise).

Required :—The tolerance on any side of a triangle that will achieve a stated tolerance on another side. (Rule 16).

Tolerance : $$a = \frac{b \times A}{B}$$

$$a = \frac{c \times A}{C}$$



R

$$b = \frac{a \times B}{A}$$

$$b = \frac{c \times B}{C}$$

$$c = \frac{a \times C}{A}$$

$$c = \frac{b \times C}{B}$$

If trigonometry has been used to find the mean figure of any side, the tolerance can be found by using the same trigonometric formulae, *i.e.*, if B × tan ∠ = C, then b × tan ∠ = c.

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25. ⅞″ ,, ,, ,, (30 ton yield).
26. 1″ ,, ,, ,, (30 ton yield).
27. ¾″ ,, ,, ,, (40 ton yield).
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29. 1″ ,, ,, ,, (40 ton yield).
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53. Helical Spring Graphs (Round Wire).
54. ,, ,, ,, (Round Wire). } Connected.
55. ,, ,, ,, (Square Wire).

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59. ,, Deflection ,, ,, ,, ,, ,,
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62. Strength of Leaf Spring.
63. Chart Showing Relationship of Various Hardness Tests.
64. Shaft Horse-Power and Proportions of Worm Gear.
65. Ring with Uniform Internal Load (Tangential Strain). Connected.
66. ,, ,, ,, ,, ,, (Tangential Stress).
67. Hub Pressed on to Steel Shaft. (Maximum Tangential Stress at Bore of Hub).
68. Hub Pressed on to Steel Shaft. (Radial Gripping Pressure between Hub and Shaft).
69. Rotating Disc (Steel) Tangential Strain. Connected.
70. ,, ,, ,, Stress.
71. Ring with Uniform External Load, Tangential Strain. Connected.
72. ,, ,, ,, ,, ,, Stress.
73. Viscosity Temperature Chart for Converting Commercial to Absolute Viscosities. Connected.
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113. Permissible Stresses in Cranes—B.S. 2573. Table 4—Power Driven Rivets and Fit Bolts.
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